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TECHNICAL REPORT  
67-13-CM

# DEVELOPMENT OF A CARBON HEATING UNIT

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by

Miles J. McGoff and Walter Milich

MSA Research Corporation  
Evans City, Pennsylvania

Contract No. DA-19-129-AMC-105 (N)

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UNITED STATES ARMY  
NATICK LABORATORIES  
Natick, Massachusetts 01760



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Contract No. DA 19-129-AMC-105(N)

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Clothing and Organic Materials Division  
U.S. ARMY NATICK LABORATORIES  
Natick, Massachusetts 01760

## FOREWORD

In one of the future feeding systems, a heater is required by combat troops to provide boiling water for the reconstitution of precooked, dehydrated Quick-Serve Meals. The heating unit must be lightweight, fast heating, inexpensive, and a one-time-use item.

Studies performed at the U. S. Army Natick Laboratories indicate that carbon fuels show promise as a heat source.

This report on the development of a carbon heating unit was prepared by Mine Safety Appliance Research Corporation, Evans City, Pennsylvania, under U. S. Army Natick Laboratories, Contract No. DA-19-129-AMC-105(N). It covers investigations made between 5 June 1963 and 5 August 1965. The principal MSA Research Corporation engineers working on the project were Miles J. McGoff and Walter Melich. Mr. David J. Kunard assisted with some of the work.

Mr. T. Kapala, of the NLABS Clothing and Organic Materials Division, served as Project Officer for this contract.

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## ABSTRACT

Experimental carbon heating units to boil water for reconstituting precooked dehydrated foods were developed at the U. S. Army Natick Laboratories and produced in contractor's pilot plant for field and laboratory study. These were designated as Phase I units. As a result of further experimentation and based on the test findings, the contractor produced an improved unit that was designated as Phase II.

Both units consisted of carbon fuel, igniter, stove support, base reflector, and shield or chimney. The Phase I fuel was a charcoal slab with perforations. The reflector was of rigid aluminum. At an ambient temperature of 68°F, this unit boiled 6 quarts of water in 10 minutes and, at an ambient temperature of 46°F, thawed snow or ice and boiled the resultant water in 22 minutes. In Phase II, several types of fuel were developed, the most promising of which was made from commercially available charcoal fuel briquettes broken into approximately 1-inch pieces. Inexpensive fiberboard and aluminum foil replaced the rigid aluminum as reflector and the stove support was made of 4 simple parts. Under the same ambient conditions, these units brought 6 quarts of water to a boil in 14 minutes and thawed snow or ice and boiled the resultant water in 30 minutes.

Although the Phase II units required slightly more heating time, their cost, estimated at about \$1.00 each in quantities of 100,000, was approximately one-fifth that of the Phase I units.

## DEVELOPMENT OF A CARBON HEATING UNIT

### I. Introduction

Through the years, the U. S. Army has provided the soldier with several types of heating units for preparing his food in the field. Of interest recently has been a heating unit that would boil the six or seven quarts of water, or thaw ice and subsequently boil the water, required to reconstitute dehydrated meal packages. The U. S. Army Natick Laboratories has been investigating the possibility of such a unit that would use charcoal as the potential low-cost fuel.

An experimental unit developed by the NLABS consisted of a perforated fuel cake (1 in. thick, 10-1/4 in. square, with 144 5/8-in. holes), an igniter, a stove support, a base reflector, and a shield for heat conservation. This unit brought 6 quarts (12-1/2 pounds) of water from ice to a boil in 21 minutes at a temperature of 50°F. and in 30 minutes at -40°F. An empty 6-in-1 meal container was used for the water. (A 25-in-1 meal container containing 3 gallons of water could also be used but would require two heating units placed side by side.) The fuel cake weighed 1.8 ( $\pm$  0.1) pounds, and the complete heater 2.8 pounds packaged in a polyethylene bag.

The schedule of contract drawn up with the MSA Research Corporation (MSARC) stated in Article I, Section A, that using the NLABS unit, "6 quarts of water can be boiled in 8-1/2 minutes at 68°F., and in 30 minutes at -40°F. It requires approximately 50 minutes to thaw snow and ice and boil the subsequent water." The performance specifications for one carbon heating unit were that it a) boil 6 to 7-1/2 quarts of water at low ambient temperatures (below freezing) in less than 15 minutes, and b) thaw snow and ice and boil the resultant water at low ambient temperatures in less than 30 minutes. General requirements were that a) the charcoal burn without smoke or odor, b) the unit be usable in sheltered but ventilated areas, c) procedures be developed and commercial carbonizing equipment used to produce the fuel, d) the efficiency be determined of fuels, such as charcoal that has been commercially produced from select wood precut to the required form, for easy ignition and rapid burning, and e) an expendable stove be developed that is light in weight and easy to assemble. Also required was that the unit have structural integrity and not be damaged or become inoperative after air drop.

It was hoped that MSARC would further develop the fuel and stove and the manufacturing methods so that ease of ignition would be improved, less carbon monoxide produced, the weight and volume of the unit decreased, and the cost reduced. To this end, several types of fuels were investigated, performance trade-offs were studied, and

value analyses were conducted. Production was divided into two phases. In Phase I, MSARC was to produce 750 units of the original NLABS design for field tests at Fort Lee (Virginia) and Fort Greely (Alaska). A Phase II production of 500 units was to incorporate design and cost improvements suggested by the data from the Phase I units and by other experimental fuels and stoves from NLABS and MSARC Labs.

Projected requirements for the carbon heating unit are on the order of one million per year. While the production of only 500 would result in a higher unit cost than would mass production, the cost as related to manufacturing methods would be projected on a mass production basis.

## II. Phase I Carbon Heating Unit

### A. Production

The 750 heating units produced by MSARC during Phase I (Fig.1) followed the experimental design developed at Natick. They included a fuel slab (with igniter strip) encased in a chicken-wire cage and wrapped in foil, a wire-frame stove to hold the fuel and support the water container, a sheet aluminum (15-mil) reflector base that lowered time to boil and served as a leveling support for the stove, and a foil chimney, plus plastic (for water-proofing) and paper wrappings, cardboard carton, and wooden crate. The total weight was 2.8 pounds.

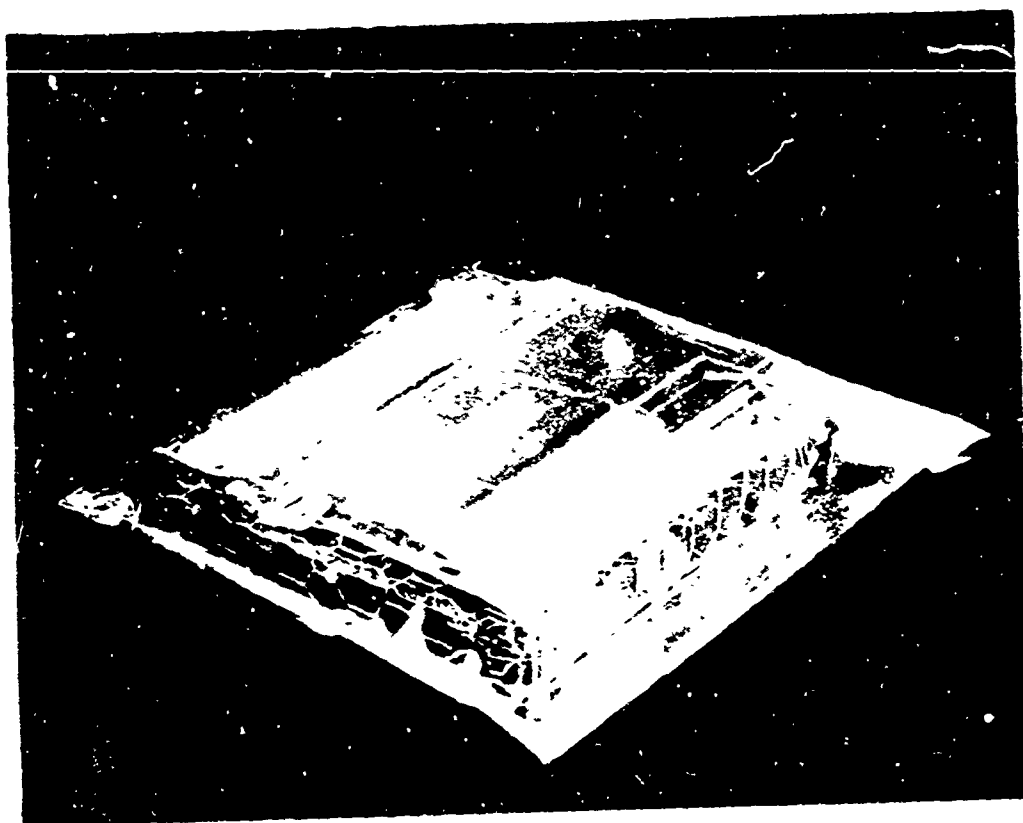
#### 1. Fuel Cakes

The fuel cakes, which were of similar composition and geometry to those developed at Natick, were made up in 25-batch lots. No scale-up problem was encountered. Performance tests, made on one cake from each batch of 25, showed the fuel to be homogeneous. Each 25-batch mix had the following ingredients:

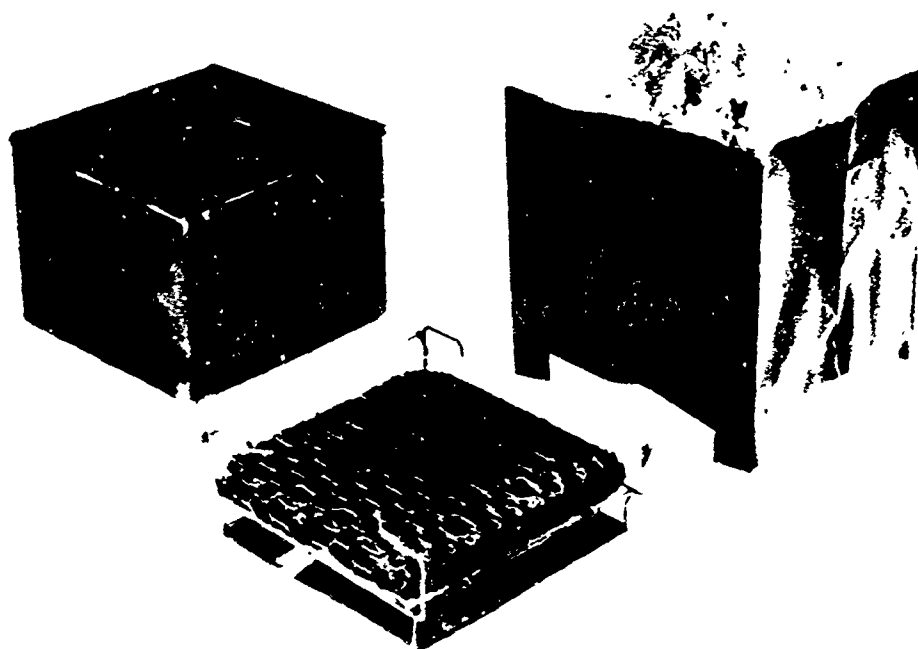
|                              |          |
|------------------------------|----------|
| Charcoal, hardwood, 300-mesh |          |
| air float                    | 35 lb    |
| Iron oxide, Glidden J-110    | 9 " 6 oz |
| Sugar                        | 6 " 4 "  |
| Starch, briquetting          | 3 " 6 "  |

MSARC found that the best method of forming and perforating the fuel cakes was by pressing and piercing them simultaneously. Extrusion was considered as an alternative method and a sample of the mix was taken to a plastic extrusion firm to ascertain if it was compatible with their equipment, for the charcoal mix is unusual in consistency and behaves somewhat like plastic putty in that it is pliant and spreads out when vibrated. However, the extrusion method was found to be impractical, not only because of the type of mix but, primarily, because of the size of the cake (10-1/4 in x 10-1/4 in x 1 in) and, further, the large capital investment required for the discs and the time-consuming labor required by the technique itself.

Although the MSARC fuel cakes were ostensibly like the experimental ones, NLABS found, upon testing some of those made during the early stage of production, that they required six minutes longer to bring water to a boil. This difference in results was



PHASE I CARBON HEATING UNIT  
(Packaged)



PHASE I CARBON HEATING UNIT  
WITH SIX-IN-ONE MEAL CONTAINER

attributed to smaller perforations in the fuel cage. The 3/8-inch rubber plugs in the die at NLABS produced 5/8-inch holes while the 3/8-inch steel plugs in the MSARC die produced 3/8-inch holes. MSARC then modified its die so that the subsequent Phase I cakes (including most of those tested in Alaska) were of the larger-hole type and were 144 to a cake.

## 2. Wire Cage

The pre-cut chicken-wire cage for the fuel cake was formed and stapled by hand. Special care was required to encase the fuel cake and igniter sheet firmly; it was a time-consuming operation.

## 3. Chimney

The chimney, or convective windshield, without which the unit would not boil water, was made from 1-1/2 mil olive drab (2 coats) Reynolds aluminum foil, 1235-0 temper, similar to Reynolds Experimental Type FX-20308. The tight production schedule necessitated that the chimneys be assembled by hand in an apparatus where the aluminum foil could be unwound, folded, and cut. Although MSARC has folding machines (used in the production of filters) and although machine folding would have lowered labor costs, the foil was too fragile to be handled in this way.

## 4. Stove, Reflector, and Igniter

While the fuel cakes, wire cage, and chimney were made by MSARC with specially adapted equipment, jigs, and tools, the stove, reflector, and igniter were made commercially according to MSARC specifications. These all proved to be expensive. Little reduction in cost was foreseen as possible, even for larger quantities of the stove and reflector, hence redesign was indicated.

The Delrin igniter was made of virgin material. It was believed that used material would reduce the cost by 60 percent.

## B. Production Cost Analysis

The Phase I unit was found to be prohibitively expensive, largely because of the preparation which involved the following time-consuming operations:

- a. Hydrolyzing the starch and sugar in a jacketed vessel equipped with an air-actuated stirrer, at 170°F.
- b. Mixing the hardwood, 300-mesh, air float charcoal with iron oxide powder; adding the starch-sugar mix; and blending into a homogeneous mass (usually water must be added to give the proper consistency).
- c. Removing the mix and placing weighed amounts into a mold that has 144 tapered pins that pierce the cake as it is pressed into shape.
- d. Stripping the molds and placing the cakes in drying ovens (a 3-man operation), where they are held at 180°F for several hours.
- e. Double-wrapping the dried cakes with pre-cut aluminum foil, with seams alternating to prevent burning during the subsequent carbonization.
- f. Carbonizing the cakes in an 800°F oven for 4 hours to reduce the starch and sugar to carbon.
- g. Carefully cooling the cakes before unwrapping (charcoal still warm from carbonization will spontaneously ignite).

The steps required by the entire operation are given in Exhibit A. Exhibit B itemizes the cost of the materials, which total \$2.33. The total cost of the Phase I unit including labor at \$3.00 per hour, was \$5.00.



## EXHIBIT A

## OPERATION SEQUENCE FOR PHASE I CARBON HEATING UNIT

| <u>No.</u> | <u>Operation Description</u>   | <u>Each Piece<br/>Time - (hr)</u> | <u>Tools</u>                                    |
|------------|--|-----------------------------------|---|
| 1          | Cut wrapping foil  | 0.0088                            | Scissors  |
| 2          | Cut chicken wire and bake  | 0.0621                            | Wire shears,<br>oven                            |
| 3          | Cellulose tabs and paint   | 0.0100                            | Scissors, spray<br>gun                          |
| 4          | Staple tabs to igniter   | 0.0078                            | Table stapling<br>fixtures                      |
| 5          | Fold, cut, form, and staple<br>chimney   | 0.1050                            | Cutting table,<br>notching and<br>table stapler |
| 6          | Prepare cake materials, mix to<br>proper consistency, weigh out<br>one cake prepack mold, finish<br>packing mold and assemble,<br>pressing and punching holes in-<br>to cake; strip; load drying<br>oven (3-man operation) | 0.4200                            | Mixer, press,<br>ovens                          |
| 7          | Unload drying oven and double-<br>wrap cakes with precut foil<br>for charring  | 0.0870                            | Bench   |
| 8          | Unload charring oven, cool<br>cakes, and unwrap  | 0.0285                            | Bench   |
| 9          | Form precut chicken wire and<br>encase cake and igniter within<br>wire; fold wire over cake and<br>assemble; hog-ring enclosed<br>cake to wire stove   | 0.0665                            | Bench   |
| 10         | Assemble contents and pack in<br>plastic bag   | 0.0385                            | Bench   |
| 11         | Heat-seal bag  | 0.0350                            | Heat sealer                                     |
| 12         | Wrap and pack bags in carton<br>(10/carton)  | 0.0140                            | Bench   |
| 13         | Pack cartons in crate, stencil,<br>and nail (10 cartons/crate)   | 0.0090                            | Stencil equip-<br>ment                          |
| Total      |  | 0.8922                            |   |

## EXHIBIT B

MATERIAL COST OF PHASE I CARBON HEATING UNIT  
(on basis of 750 units)

| <u>Item</u> |                                     | <u>Unit Cost</u><br><u>(\$)</u> |
|-------------|-------------------------------------|---------------------------------|
| 1           | Fuel                                |                                 |
|             | Charcoal                            | 0.0650                          |
|             | Iron oxide                          | 0.0319                          |
|             | Sugar                               | 0.0316                          |
|             | Starch, briquetting                 | 0.0135                          |
| 2           | Stove                               | 0.1420                          |
| 3           | Base reflector (aluminum)           | 0.7500                          |
| 4           | Delrin igniter                      | 0.4500                          |
| 5           | Delrin igniter                      | 0.1893                          |
| 6           | Chimney, aluminum foil              | 0.2120                          |
| 7           | Plastic bag                         | 0.0467                          |
| 8           | Fuel cage                           | 0.0737                          |
| 9           | Fuel cage rings                     | 0.0300                          |
| 10          | Wrapping foil, aluminum             | 0.0723                          |
| 11          | Instruction sheet                   | 0.0500                          |
| 12          | Packing paper                       | 0.0340                          |
| 13          | Cardboard cartons                   | 0.0277                          |
|             | Wood crate, prorated over 750 units | <u>0.2500</u>                   |
|             | Total                               | \$2.3277                        |

### C. Test Results

#### 1. Cold Weather Performance

Performance tests conducted on 500 Phase I units at -40°F in Alaska were favorable (USATECOM #7-3-0258-02K (Service Test-Alaska), substantiating results that had been obtained in the NLABS Arctic Chambers (Table I). In Natick, the performance of both the 3/8- and 5/8-inch holed fuel cakes of Phase I was compared with that of fuel cakes made at NLABS and of other experimental fuels, one of which was a perforated hardwood slab directly carbonized at 800°F in a commercial retort. The hardwood slab had poor heating performance. Shrinkage and distortion also detracted from the direct carbonization of hardwood board as a fuel.

#### 2. Carbon Monoxide Production

At Fort Lee Virginia the U. S. Army General Equipment Test Activity (GETA) conducted a carbon monoxide concentration study of Phase I units in 5-man Army tents and reported that the units did not produce dangerous levels of CO. However, in tests made by MSARC, where an Army tent was monitored by an MSA Model 300 Carbon Monoxide Lira, CO in excess of 100 ppm was recorded. This level is considered to be harmful. MSARC also measured CO production in a closed (unventilated) 4000-cubic foot chamber, with results as shown in Figure 2. MSA findings corroborate the assumption that ventilation is a factor in CO concentration but that, under proper conditions it should be possible to avoid harmful CO accumulations.

### III. Experimental Program

The experimental program was divided into physical and chemical investigations. The physical investigations included the geometry of the fuel cakes as well as of the briquette; also the distance between the fuel and the water container and the fuel and base reflector. The chemical investigations encompassed primarily the fuels and the igniter components of the carbon heating unit and their influence on performance.

#### A. Physical Investigations with Fuels

##### 1. Fuel Cake of Phase I

Results of combustion and geometry tests are shown in Tables II and III (pp 12.13 and 14), where cake size and composition and hole size and shapes were varied. No improvement was observed when the

TABLE I

## Cold Weather Performance at NLABS of Phase I Heaters

| Fuel<br>(No.) | Water at Start |          | Time from Start (min) |              | Heat Delivery, Btu |             |                        |
|---------------|----------------|----------|-----------------------|--------------|--------------------|-------------|------------------------|
|               | State          | Temp(°C) | To Boil               | To Stop Boil | (per min)**        | (per lb)*** |                        |
| MSA-ET*       | liquid         | + 3.0    | 38.0                  | ---          | ---                | ---         | -18°C,<br>20 mph wind  |
| MSA-ST        | solid          | -16.7    | 22.0                  | 38           | 218                | 2960        |                        |
| 121A-Br       | liquid         | + 0.7    | 13.0                  | 29           | 179                | 1935        |                        |
| MSA-ET*       | solid          | -27.0    | 43.0                  | ---          | ---                | ---         | -28°C,<br>3-4 mph wind |
| MSA-ST        | liquid         | + 7.8    | 12.8                  | 60           | 145                | 3025        |                        |
| MSA-ST        | solid          | -31.1    | 29.2                  | 65           | 132                | 4120        |                        |
| 121A-Br       | solid          | -30.0    | 28.5                  | 64           | 147                | 3550        |                        |
| 121A-Su       | liquid         | + 1.7    | 26.0                  | 59           | 73                 | 2633        |                        |
| MSA-ET*       | liquid         | + 5.0    | 26.5                  | ---          | ---                | ---         | -40°C,<br>3-4 mph wind |
| MSA-ET*       | solid          | -35.5    | 41.0                  | ---          | ---                | ---         |                        |
| MSA-ST        | liquid         | +12.5    | 14.8                  | 63           | 123                | 3303        |                        |
| 121A-S1       | solid          | -36.9    | 31.5                  | 67           | 131                | 2750        |                        |
| 121A-S1       | liquid         | + 7.8    | 13.0                  | 59           | 165                | 3170        |                        |
| MSAR-4        | liquid         | + 1.7    | 36.0                  | 56           | 69                 | 4460        | -40°C,<br>4 mph wind   |
| MSAR-5        | liquid         | + 0.0    | 58.0                  | 80           | 40                 | 2650        |                        |
| MSAR-6        | liquid         | + 4.4    | 26.0                  | 70           | 79                 | 2720        |                        |

\*Tests conducted at NLABS by GETA (U.S. Army General Equipment Test Activity, Fort Lee, Va.)

Fuel Code: MSA-ET = mfd by MSARC 3/8 in. holes also tested by GETA (Eng. Test)  
 MSA-ST = mfd by MSARC 5/8 in. holes (Service Test)  
 121A-Br = made at NLABS corrugated oval briquettes with hardwood charcoal and iron oxide  
 121A-Su = made at NLABS an uncarbonized slab  
 121A-S1 = made at NLABS hardwood charcoal and iron oxide slab, carbonized  
 MSAR-5 = mfd by MSARC carbonized block of white oak, with holes  
 MSAR-4,6 = NLABS slabs carbonized in retorts of Otto Chem. Co. for MSARC

\*\*Btu per minute measured from initial temperature to 71°C.

\*\*\*Btu per pound measured from initial temperature to end of boil.

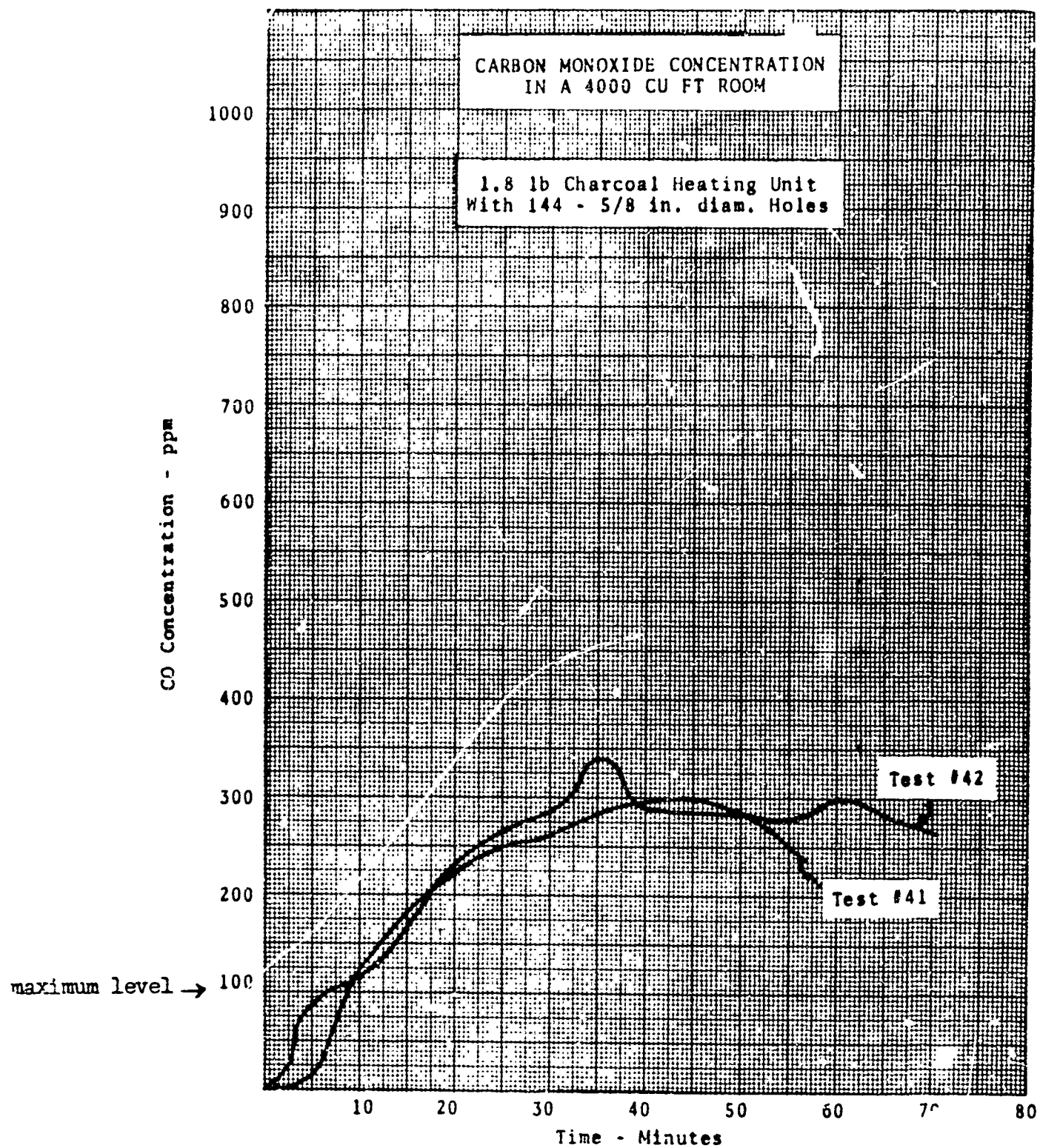


FIG. 2 - CO CONCENTRATION IN CLOSED CHAMBER -  
PHASE I CARBON HEATING UNIT

TABLE II - COMBUSTION TESTS WITH CHARCOAL FUEL CAKES

Charcoal Fuel Cake

Composition: Charcoal - 64.8%  
 Starch - 6.2%  
 Sugar - 11.6%  
 Iron Oxide - 17.4% (Glidden J-110)

Igniter: Delrin Sheet, 10 mil thick (except No. 14 & 16, which were Celcon)

Tests Conducted with Water Container and Heat Shield

| Test No. | Fuel Cake Description                        | Weight (gms) | Temp (°F) |       | Wind Velocity (MPH) | Time to Boil min-sec | Total Time (min) | Water Evap. lb-oz | Therm. Eff. (%) | Remarks  |
|----------|--|--------------|-----------|-------|---------------------|----------------------|------------------|-------------------|-----------------|--|
|          |  |              | Ambient   | Water |                     |                      |                  |                   |                 |  |
| 1        | 144-3/8 in. dia. holes                       | 810          | 69        | 74    | 2-5                 | 14-33                | -                | 8-13              | 46              | Glidden A-130 iron powder in fuel.   |
| 2        | 144-3/8 in. dia. holes                       | 783          | 69        | 72    | Slight              | 18-0                 | -                | 6-8               | 38              | Glidden A-130 iron powder.   |
| 3        | 144-3/8 in. dia. holes                       | 724          | 75        | 74    | 0-5                 | 16-45                | 89               | 6-0               | 40              | Used 15 lb water, A-130 iron in fuel.  |
| 4        | 144-3/8 in. dia. holes                       | 796          | 77        | 82    | 5-10                | 14-0                 | 81               | 7-9               | 41              | Used 15 lb water, A-130 iron in fuel.  |
| 5        | 144-3/8 in. dia. holes                       | -            | 67        | 69    | 3-5                 | 15-15                | -                | -                 | -               | Fuel cake the type sent to Ft. Lee. This fuel and subsequent fuel cakes prepared with iron oxide (Glidden J-110).  |
| 6        | 144-3/8 in. dia. holes                       | 893          | 60        | 42    | 0                   | 19-55                | 85               | 5-8               | 38              | Smoked considerably.   |
| 7        | 144-3/8 in. dia. holes                       | -            | 72        | 72    |                     |                      |                  |                   |                 | Test made in combustion chamber, data collected on CO vs time.   |
| 8a       | 144-3/8 in. dia. holes                       | -            | 72        | 72    | -                   | 13-30                | -                | -                 | -               | Test conducted to compare MSAR fuel cake with QMC fuel. Fuel cake 8b prepared with sponge iron, 8c with internal igniter (nitrates) and smoked.  |
| 8b       | 144-3/8 in. dia. holes (NLABS)               | -            | 72        | 76    | -                   | 10-30                | -                | -                 | -               |  |
| 8c       | Perforated 10 in. sq. cake (NLABS)           | -            | 72        | 68    | -                   | 50-0                 | -                | -                 | -               |  |
| 9a       | 144-3/8 in. dia. holes                       | 843          | 74        | 71    | 3-5                 | 16-0                 | -                | -                 | -               | Repeat of run 8. Again showed that larger holes in QMC fuel cake 9b, was more rapid in bringing water to a boil. Fuel cake 9b contained Glidden J-110 iron oxide, 9c internal igniter. |
| 9b       | 144-3/8 in. dia. holes (NLABS)               | -            | 74        | 68    | -                   | 11-30                | -                | -                 | -               |  |
| 9c       | Perforated 10 in. sq. cake (NLABS)           | -            | 74        | 78    | -                   | 19-20                | -                | -                 | -               |  |
| 10a      | 144-3/8 in. dia. holes                       | -            | 74        | 79    | -                   | 11-50                | 54               | -                 | -               | Study effect of larger taper hole. Definite help to have igniter tabs to start off.  |
| 10b      | 144-3/8 in. dia. holes                       | -            | 74        | 68    | -                   | 17-45                | 67               | -                 | -               |  |
| 11a      | 144-3/8 in. dia. holes                       | 817          | 76        | 68    | 0-2                 | 13-15                | 65               | -                 | -               | Appears taper hold is helpful, nitrocellulose tabs used with Delrin igniter to this test.  |
| 11b      | 144-5/8 in. to 3/8 in. dia. holes            | 821          | 76        | 71    | 0-2                 | 11-25                | 65               | -                 | -               |  |
| 12a      | 144-3/8 in. dia. holes                       | 923          | 82        | 74    | 10-20               | 21-0                 | 82               | -                 | -               | Delrin tabs used hereafter on Igniter sheet. Comparison run to check taper.  |
| 12b      | 144-5/8 in. dia. holes to 3/8 in. dia. holes | 880          | 82        | 74    | 10-20               | 17-35                | 77               | -                 | -               |  |
| 13a      | 144-3/8 in. dia. holes                       | 833          | 69        | 68    | 0-10                | 16-55                | -                | -                 | -               | Deepen grooves.  |
| 13b      | 144-3/8 in. dia. holes                       | 846          | 69        | 69    | 0-10                | 19-20                | -                | -                 | -               | Filed surface and holes. As is.  |
| 13c      | 144-3/8 in. dia. holes                       | 865          | 69        | 68    | 0-10                | 16-45                | -                | -                 | -               |  |
| 13d      | 144-3/8 in. dia. holes                       | 888          | 69        | 68    | 0-10                | 20-20                | -                | -                 | -               | Filed surface - holes. (13a,b,c,d) Run to check effect of roughing surfaces. Not much help. Hole size more critical.   |
| 14       | 144-3/8 in. dia. holes                       | 827          | 90        | 70    | 0-5                 | 16-15                | -                | -                 | -               |  |

\*See Appendix B for sample calculation

TABLE II - COMBUSTION TESTS WITH CHARCOAL FUEL CAKES (Contd)

| Test No. | Fuel Cake Description                                  | Weight (gms) | Temp (°F) |            | Wind Velocity (MPH) | Time to Boil min-sec | Total Time (min) | Water Evap. lb-oz | Therm. Eff. (%) | Remarks  |
|----------|--|--------------|-----------|------------|---------------------|----------------------|------------------|-------------------|-----------------|--|
|          |  |              | Ambient   | Water      |                     |                      |                  |                   |                 |  |
| 15       | 1 1/4-3/8 in. dia. holes                               | 650          | 78        | 65         | 0                   | 10-30                | -                | -                 | -               | Tested in comb. chamber.   |
| 16       | 1 1/4-3/8 in. dia. holes                               | 695          | 78        | 70         | 0                   | 10-30                | -                | -                 | -               | Celcon igniter. 0.010" thick. Test in combustion chamber. Strong odor.   |
| 17       | 1 1/4-5/8 to 1/2 in. taper dia. holes                  | 775          | 72        | 68         | 3-5                 | 11-50                | 65               | -                 | -               | To check tapered holes.  |
| 18       | 1 1/4-1/2 in. dia. holes                               | 745          | 72        | 68         | 3-5                 | 12-50                | 53               | -                 | -               | Check 1/2 in. dia. hole vs previous 3/8" holes.  |
| 19       | 1 1/4-1/2 in. dia. holes (Repeat of 18)                | 745          | 58        | 66         | 0-5                 | 12-30                | -                | -                 | -               |  |
| 20       | 1 1/4-5/8 in. x 1/2 in. taper                          | 762          | 58        | 67         | 0-5                 | 10-45                | -                | -                 | -               | Larger dia. holes are beneficial.  |
| 21a      | 1 1/4-5/8 in. x 1/2 in. taper                          | 792          | 71        | 70         | 0                   | 10-25                | 51               | -                 | -               | The 5/8 in. dia. holes look best thus far.   |
| 21b      | 1 1/4-5/8 in. x 1/2 in. taper                          | 765          | 71        | 68         | 0                   | 10-50                | 49               | -                 | -               |  |
| 22a      | 1 1/4-5/8 in. x 1/2 in. taper                          | 818          | 77        | 74         | 2-5                 | 12-45                | 55               | -                 | -               | Check std. heat prod. batch and check cake weight vs time to boil.   |
| 22b      | 1 1/4-5/8 in. x 1/2 in. taper                          | 707          | 77        | 75         | 2-5                 | 12-4                 | 55               | -                 | -               |  |
| 23       | 1 1/4-5/8 in. x 1/2 in. taper                          | -            | 61        | 68         | 0-10                | 11-15                | 52               | -                 | -               | Flaming all way to boiling time. Box coated with white residue. Did not appear to improve boiling time. Appears that heavier cake is slower in boiling. (higher density) does burn longer. |
| 24a      | 1 1/4-5/8 in. x 1/2 in. taper (lighter cake)           | 762          | 83        | 70         | 0-2                 | 11-15                | 51               | -                 | -               |  |
| 24b      | 1 1/4-5/8 in. x 1/2 in. taper (heavier cake)           | 823          | 83        | 21         | 0-2                 | 16-30                | 62               | -                 | -               |  |
| 25a      | 1 1/4-5/8 in. x 1/2 in. taper                          | 712          | 52        | 68         | 0-2                 | 10-15                | 55               | -                 | -               | Weight difference may mask cracked vs whole cake.  |
| 25b      | 1 1/4-5/8 in. x 1/2 in. taper (cracked or broken cake) | 763          | 52        | 65         | 0-2                 | 12-0                 | 55               | -                 | -               |  |
| 26a      | 1 1/4-5/8 in. x 1/2 in. taper (mold clean at start)    | 780          | 83        | 73         | 5-8                 | 13-0                 | 54               | -                 | -               | Looks like dirty mold does not allow full penetration of pins through cake.  |
| 26b      | 1 1/4-5/8 in. x 1/2 in. taper (mold dirty at end)      | 770          | 83        | 68         | 5-8                 | 14-10                | 55               | -                 | -               |  |
| 27a      | 1 1/4-5/8 in. dia. holes                               | 779          | 45        | 68         | 0                   | 9-50                 | 52               | -                 | -               | Check production cake. Both cracked slightly. Took Delrin 2-1/2 min. to burn completely. Test 27a from heat 15, test 27b heat 16.  |
| 27b      | 1 1/4-5/8 in. dia. holes                               | 774          | 45        | 64         | 0                   | 11-15                | 53               | -                 | -               |  |
| 28a      | 1 1/4-5/8 in. dia. holes                               | 818          | 52        | 63         | 0-5                 | 12-10                | 62               | -                 | -               | Tests measure time to melt ice and boil, compared to water. Ambient air at 52°F. Ice subcooled in cold box. Cakes from Heat 17, Type sent Ft. Greely, Alaska.                              |
| 28b      | 1 1/4-5/8 in. dia. holes                               | 816          | 52        | -109 (ice) | 0-5                 | 28-30                | 65               | -                 | -               |  |
| 29a      | 1 1/4-5/8 in. dia. holes                               | 816          | 50        | -109 (ice) | 2-5                 | 20-55                | -                | -                 | -               | Fuel cakes in test 29a and 29b from Heat 18.   |
| 29b      | 1 1/4-5/8 in. dia. holes                               | 813          | 50        | 68         | 2-5                 | 12-7                 | 55               | -                 | -               | 29c fuel cake from Heat 8. Tests compared two heats; no appreciable difference; and variation in time to boil water as opposed to ice.   |
| 29c      | 1 1/4-5/8 in. to 1/2 in. dia.                          | 800          | 50        | 67         | 2-5                 | 11-0                 | 50               | -                 | -               |  |

TABLE III - COMBUSTION TESTS BASED ON GEOMETRY OF CHARCOAL FUEL CAKES

Charcoal Fuel Cakes

Size: 10-1/4 in. x 10-1/4 in.  
 Composition: Charcoal - 64.8%  
                   Starch - 6.2%  
                   Sugar - 11.6%  
                   Iron Oxide - 17.4% (Glidden J-110)  
 Igniter: Delrin Sheet, 10 mil thick  
 Tests Conducted with 6-1/2 qts Water and Heat Shield

| Test No. | Fuel Cake Description   | Ratio Surface to Volume (1/ft) | Weight (of Cake) (gms) | Temp °F |       | Wind Velocity (MPH) | Time to Boil (min-sec) | Total Time (min) | Water Evap. (lb-oz) | Thermal Eff. (%) | Remarks  |
|----------|---|--------------------------------|------------------------|---------|-------|---------------------|------------------------|------------------|---------------------|------------------|--|
|          |   |                                |                        | Ambient | Water |                     |                        |                  |                     |                  |  |
| 38a      | 169-1/2 in. square holes - cake 1-1/4 in. thick   | 96                             | 957                    | 53      | 61    | 0                   | 11-30                  | 57               | 9 - 2               | 40.8             | Some of the charcoal fell off in chunks.   |
| 38b      | 121-7/16 in. hex shape holes - cake 1-1/4 in. thick   | 147                            | 825                    | 53      | 62    | 0                   | 11-30                  | 57               | 7 - 4               | 39.2             | Test was production fuel cake of type supplied in Phase 1 and was conducted as basis of comparison, all tests made this way. |
| 38c      | 144-5/8 in. dia. holes - cake 1 in. thick (Std. production cake)  | 87                             | 790                    | 53      | 64    | 0                   | 11-30                  | 57               | 7 - 0               | 39.8             |  |
| 39a      | 144-5/8 in. square holes - cake 1-1/8 in. - 1-1/4 in. thick   | 122                            | 955                    | 46      | 58    | 0-20                | 12-30                  | 61               | 8 - 2               | 37.7             | Standard production type cake, ran for comparison.   |
| 39b      | 160-7/16 in. hex holes - cake 1-1/8 in. - 1-1/4 in. thick   | 102                            | 930                    | 46      | 58    | 0-20                | 12-30                  | 63               | 7 - 1               | 34.3             | Standard production type cake, ran for comparison.   |
| 39c      | 144-5/8 in. dia. holes (Std. production cake)   | 87                             | 807                    | 46      | 64    | 0-20                | 11-0                   | 55               | 6 - 8               | 36.7             | Stand. production type cake, ran for comparison.   |
| 40a      | 169-1/2 in. dia. holes - cake 1-1/4 in. thick   | 75                             | 963                    | 40      | 58    | 0-20                | 15-0                   | 62               | 7 -11               | 34.8             |  |
| 40b      | 144-5/8 in. dia. holes. Pivoted stove used. Cake not encased in chicken wire.   | 87                             | 801                    | 40      | 60    | 0-20                | 13-0                   | 50               | 4 - 7               | 29.2             | Rack flattened out and food container dropped down in 25 min.  |
| 40c      | 144-5/8 in. dia. holes (Std. production cake)   | 87                             | 812                    | 40      | 65    | 0-20                | 16-30                  | 62               | 5 -14               | 33.8             | Standard type production fuel cake and stove.  |
| 43a      | 5/8 in. OD x 1-3/4 in. long extrusions encased in 10-1/4 in. x 10-1/4 in. x 1 in. basket made 5/16 in. square mesh screen | 79                             | 800                    | 35      | 58    | 0-15                | 19-30                  | 70               | 5 -13               | 34.4             |  |
| 43b      | 144-5/8 in. dia. holes, cake sprayed with Plastic-Kote  | 87                             | 844                    | 35      | 60.8  | 0-15                | 15-0                   | 58               | 7 - 3               | 38.1             |  |
| 43c      | 144-5/8 in. dia. holes (Std. production cake)   | 87                             | 804                    | 35      | 58    | 0-15                | 12-30                  | 54               | 6 -10               | 37.9             |  |



number or the size of the holes was changed from the 144 5/8-inch holes of the Phase I reduction. No advantage was obtained by changing the shape of the hole from round to hexagonal or square. In conducting this investigation, the performance of the fuel cakes prepared at the NLABS was also studied. These were of the same Phase I configuration.

The feasibility of directly manufacturing the cake from a solid slab of wood was investigated. Hardwood slabs, approximately the same size as the 10-in-square fuel cake could be processed directly. In the carbonizing of the hardwood block, the high temperatures required caused shrinkage and distortion. The block was relatively fragile and performed poorly.

Manufacturing techniques studied in the experimental program were considered in view of the application to commercial apparatus. The carbonizing of the hardwood boards was done at a commercial carbonizing facility, - the Otto Chemical Company in Kane, Pennsylvania. The performance of a carbonized hardwood block is given in Table I (see No. MSAR-5).

## 2. Briquettes of Phase II

Briquettes were extensively investigated because of their inherently low cost. Peach pits, which were also considered as a source of fuel, did not prove efficient in their combustion properties.

Information about the production of charcoal is proprietary to the charcoal manufacturers. Consequently, little could be learned from them. One low-cost charcoal obtained from the Quaker Oats Company is unique because the briquettes are made by extrusion and the source of the raw material is the char remaining after the manufacture of furfural from corn cobs.

Table IV shows performance results obtained with briquette fuels including peach pits. The effect of sponge iron oxide in the blend is shown by comparing Tests 60 and 61. Calculations based on CO and CO<sub>2</sub> measurements show that sponge iron oxide reduced CO output by approximately one-half in the hardwood charcoal briquettes. Therefore, the addition of sponge iron oxide is worthwhile with hardwood; however, it does add to the cost. The processing of briquettes with sponge iron oxide by extrusion was discussed with the Quaker Oats Company. In their judgment, extrusion would be difficult and development work would be necessary. However, experiments conducted by NLABS indicated that no reduction of CO output occurred when sponge iron oxide was added to the Quaker Oats material. This is also shown by comparing tests 55, 56, and 77 with test 70 (See Table VI p23 ).

TABLE IV - BRIQUETTE FUEL TESTS - PHASE II

| Tests conducted with 6 qts. water and 12 in. chimney |  |              |                 |               |               |                          |                   |                        |                          |                    |                    |                  |
|--|--|--------------|-----------------|---------------|---------------|--------------------------|-------------------|------------------------|--------------------------|--------------------|--------------------|------------------|
| Fuel Tray - 10 in. square<br>Igniter - Delrin Sheet  |  |              |                 |               |               |                          |                   |                        |                          |                    |                    |                  |
| Test No.   | Fuel Type  | Weight (gms) | Amb. Temp. (°F) | Max. CO (ppm) | Avg. CO (ppm) | Avg. CO <sub>2</sub> (%) | Total* CO (cu ft) | Ratio* (cu ft CO/lb C) | Burning* Rate (lb C/min) | Time to Burn (min) | Time to Boil (min) | Thermal Eff. (%) |
|  |  |              |                 |               |               |                          |                   |                        |                          |                    |                    |                  |
| 55   | Briquettes, 55°F, Quaker Oats Company 7/8-in. thick with 1/4-in. hole. | 722          | 56              | 2000          | 698           | 0.36                     | 9.20              | 5.81                   | 0.0171                   | 94                 | 17                 | 38               |
| 56   | Same as above.   | 678          | 48              | 2000          | 1280          | 0.36                     | 15.90             | 10.60                  | 0.0205                   | 85                 | 16                 | 28               |
| 57   | Briquettes, Quaker Oats Company, cut 1/2-in. thick with 1/2-in. hole.  | 400          | 40              | 1380          | 1020          | 0.29                     | 9.25              | 10.50                  | 0.0136                   | 65                 | 24                 | 34               |
| 78   | Briquettes**, MEAR 2 in. donuts, 7/8-in. thick with 3/4-in. hole.      | 571          | 40              | 720           | 340           | 0.41                     | 3.10              | 3.10                   | 0.0228                   | 55                 | 13-1/2             | 41               |
| 49b  | Peach Pits   | 680          | 20              | --            | --            | --                       | --                | --                     | --                       | --                 | 50                 | --               |
| 60   | Briquettes, ** MEAR 2 in. donuts, 7/8-in. thick with 5/8-in. hole.     | 518          | 48              | 720           | 356           | 0.42                     | 2.42              | 2.60                   | 0.0164                   | 60                 | 14-1/2             | 38               |
| 61   | Briquettes, MEAR*** 2 in. donuts, 7/8-in. thick with 5/8-in. hole.     | 343          | 50              | 1600          | 750           | 0.42                     | 3.35              | 5.40                   | 0.0108                   | 60                 | 14                 | 45               |
| 43a  | Charcoal** extrusions 5/8 in. OD x 1-3/4 in. long.                     | 800          | 35              | --            | --            | --                       | --                | --                     | 0.0110                   | 54                 | 19-1/2             | 34               |

\*See Appendix B for sample calculation.

\*\*Composition same as fuel cakes.

\*\*\*Composition same as fuel cakes except no iron oxide.

### 3. Briquette Extrusion

The process of extruding charcoal was investigated with configurations as shown in Figure 3. Briquettes were extruded from a mold through a die by means of a hydraulic press. These briquettes were prepared from 300-mesh air float charcoal and briquetting starch mixture. These briquettes were successfully ignited to boil water in about 17 minutes. The briquettes, about 2 inches in size, had a central 5/8-inch hole. One form was shaped similarly to a Maltese Cross, another was round, like a doughnut. The performance of these briquettes was comparable with those of the Quaker Oats Company. The extrusion of a perforated cake one quarter the size of that supplied in Phase I was also attempted. Difficulties were encountered in that water squeezed from the mold, the charcoal mix compacted, and pressure to move the mix became excessively high. The extruding pointed out that a carefully prepared mixture is necessary. An extrusion process would require special control in the manufacturing process.

The extrusion process is unique because of the gear-shaped style of briquettes manufactured. The gears (2 in. in diameter and with a central 1/4-in. hole) provide numerous kindling edges for ignition, consequently, good starting characteristics are obtained with this type of briquette. These briquettes are sold commercially with hickory as an additive. The hickory is undesirable for this application because of its smoke and odor-producing properties. In the course of this work, the Quaker Oats Company was cooperative in providing briquettes without hickory, with 5/8-inch holes, and in several thicknesses.

Pure Oil Company also provided briquettes for this experimental program. These were rounded, impregnated with an oil base to give self-igniting characteristics, and were packaged in a Mylar bag. The odor from these briquettes was quite objectionable and, therefore, they were unacceptable for this application.

The Quaker Oats Company briquettes were subjected to extensive testing. The optimum arrangement was obtained by crushing them into granules approximately one-quarter the original size (about No. 2 mesh). Table V lists the results of the fuel evaluation tests with gear-shaped briquettes, both crushed and uncrushed. These briquettes were packaged in a fuel tray approximately 10 inches by 10 inches and 1-1/2 inches high. Ignition was further improved by placing several pieces of the fuel underneath the igniter sheet. This arrangement was ultimately used in the Phase II carbon heating unit that was delivered to the Natick Laboratories.

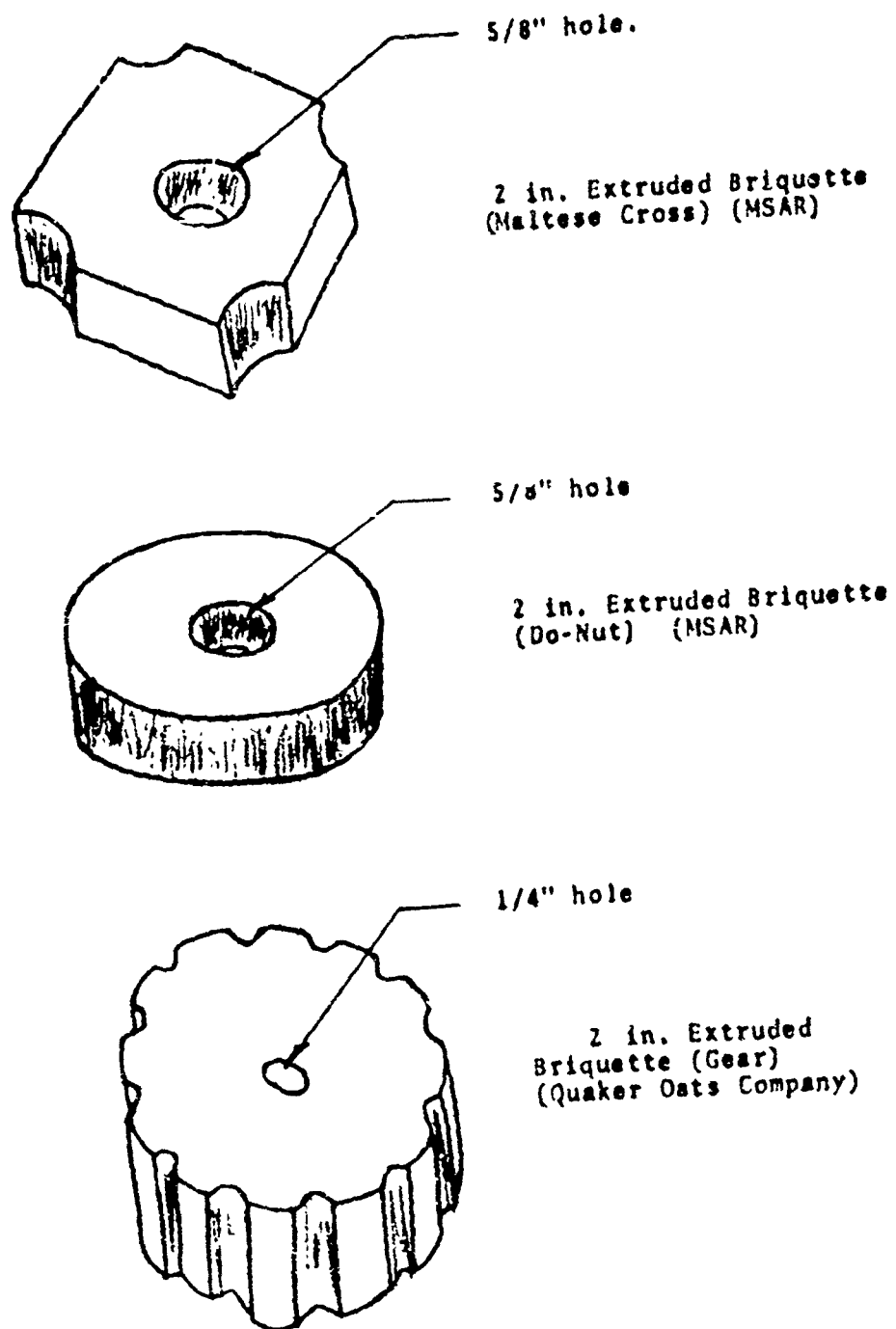


FIG. 3 - EXTRUDED CHARCOAL BRIQUETTES

TABLE V - RESULTS OF FUEL EVALUATION TESTS - PHASE II -  
ON  
GEAP-SHAPED BRIQUETTES

(12 in. high chimney, aluminum foil reflector, 10 in. x 10 in. fuel tray  
Delrin igniter, MSAR in-house 4-point stove)

Tests conducted with 6 qts. water or ice

| Test Set | Nominal Thickness (in.) |     |       | Briquettes Packaging in Trays |           |          | Processing |           | Amb. Temp. (°F) | Fuel Cage Wire Mesh Size No. | Time to Boil (min) |        | Remarks  |
|----------|-------------------------|-----|-------|-------------------------------|-----------|----------|------------|-----------|-----------------|------------------------------|--------------------|--------|--|
|          | 5/8                     | 7/8 | 1 1/4 | Uniform                       | Scattered | Other    | Carb.      | Non-Carb. |                 |                              | Ice                | Water  |  |
|          |                         |     |       |                               |           |          |            |           |                 |                              |                    |        |  |
| 1        | x                       |     |       | x                             |           |          |            | x         | 50              | 1                            | -                  | 16     | Satisfactory structural design                                     |
|          |                         |     | x     |                               |           |          |            | x         | 50              | 1                            | -                  | 23-1/4 |  |
| 2        |                         |     |       | x                             |           |          |            | x         | 40              | 1                            | 42                 | -      | Satisfactory structural design 3-mesh fuel cage difficult to light |
|          |                         |     |       | x                             |           |          |            | x         | 40              | 2                            | 45                 | -      |  |
|          |                         |     |       | x                             |           |          |            | x         | 40              | 3                            | 45                 | -      |  |
| 3        | x                       |     |       | x                             |           |          |            | x         | 22              | 1                            | -                  | 18     | Satisfactory   |
|          | x                       |     |       |                               |           | Broken*  |            | x         | 22              | 2                            | -                  | 14     |  |
|          | x                       |     |       |                               | x         |          |            | x         | 22              | 2                            | -                  | 16 1/4 |  |
| 4        | x                       |     |       | x                             |           |          |            | x         | 28              | 2                            | 44                 | -      | "  |
|          |                         | x   |       | x                             |           |          |            | x         | 28              | 2                            | 41-1/2             | -      |  |
|          | x                       |     |       | x                             |           |          |            | x         | 28              | 2                            | 41-1/2             | -      |  |
| 5        |                         | x   |       | x                             |           |          |            | x         | 8               | 2                            | 48                 | -      | "  |
|          | x                       |     |       |                               |           | on end   |            |           | 8               | 2***                         | 49                 | -      |  |
| 6        | x                       |     |       |                               | x         |          |            | x         | 20              | 2                            | 37                 | -      | Stove collapsed.   |
|          | x                       |     |       |                               |           | Broken** |            | x         | 20              | 2                            | 28                 | -      |  |
|          | x                       |     |       | x                             |           |          |            | x         | 20              | 2                            | 47                 | -      |  |
| 7        | x                       |     |       |                               |           | Broken** |            | x         | 14              | 2                            | 25-3/4             | -      | Stoves and aluminum foil were satisfactory.                        |
|          | x                       |     |       |                               |           | Broken** |            | x         | 14              | 2                            | 22                 | -      |  |
|          | x                       |     |       |                               |           | Broken** |            | x         | 14              | 2                            | 28                 | -      |  |
| 8        | x                       |     |       |                               |           | Broken*  |            | x         | 50              | 2                            | 23                 | -      | Unit cold soaked at 49°F. Stove collapsed.                         |
|          | x                       |     |       |                               |           | Broken*  |            | x         | 50              | 2                            | 28                 | -      |  |
| 9        | x                       |     |       |                               |           | Broken*  |            | x         | 20              | 2                            | 22-1/2             | -      | Unit cold soaked.  |
|          | x                       |     |       |                               |           | Broken*  |            | x         | 20              | 2                            | 24                 | -      |  |
| 10       | x                       |     |       |                               |           | Broken*  |            |           | 35              | 2                            | 22                 | -      | Units cold soaked at -60°F.  |
|          | x                       |     |       |                               |           | Broken*  |            | x         | 35              | 2                            | 22                 | -      |  |

\* - broken in quarters  
\*\* - broken in halves  
\*\*\* - 8 in. x 8 in. tray

## B. Chemical Investigations With Fuels

Chemical means of improving combustion efficiency were investigated with carbon fuels and with the igniter. Combustion improvements that were possible, however, were found to be impractical from the standpoint of cost, odor, and manufacturing methods.

Both the fuel cakes of Phase I and the briquettes used in Phase II were investigated. The CO output from the Quaker Oats Briquettes was higher than from the fuel cakes.

### 1. Fuel Cakes of Phase I

The fuel cakes, of the configuration used in Phase I, were prepared with the chemical agents dried, charred, and ignited. The cakes were tested in a combustion cell (Fig. 4) and monitored for CO. The CO concentration in the flue was plotted against time (Fig. 5). The iron oxide was shown to be the most effective agent for lowering the CO level and manganese powder was the next most effective. A fuel cake prepared with no additives (No. 71) evolved more CO per pound of carbon than did any of the other specially treated cakes (approximately seven times that evolved by a cake with iron oxide). These data are given in Table VI. Since CO is evolved, the use of any additive may not be warranted for this application.

The fuel cakes discussed above were prepared with air-float type charcoal. A very interesting phenomenon resulted from the cake in which potassium permanganate was added (No. 82). This cake possessed spontaneous ignition properties, hence theoretically would not require an igniter sheet or matches. All charcoal spontaneously ignites after carbonizing when subjected to the proper conditions. The addition of potassium permanganate extends the spontaneous ignition properties. This blend possessed self-ignition properties even after 48 hours, which is the cooling time required by ICC before shipment.

In general, the combustion of charcoal fuel cakes blended with additives was more rapid.

1. The more porous the fuel cake, the more rapid was combustion. In some cases, as little as 7-1/4 minutes was required to bring 6 quarts of water to a boil. This was thought to be primarily due to increased porosity of the cake rather than to the additive.
2. Perforated fuel cakes burn more rapidly than the briquettes. Evidently the holes permit more air flow than is possible with briquettes.

Gas Sample to MSA CO LIRA  
and MSA CO<sub>2</sub> LIRA

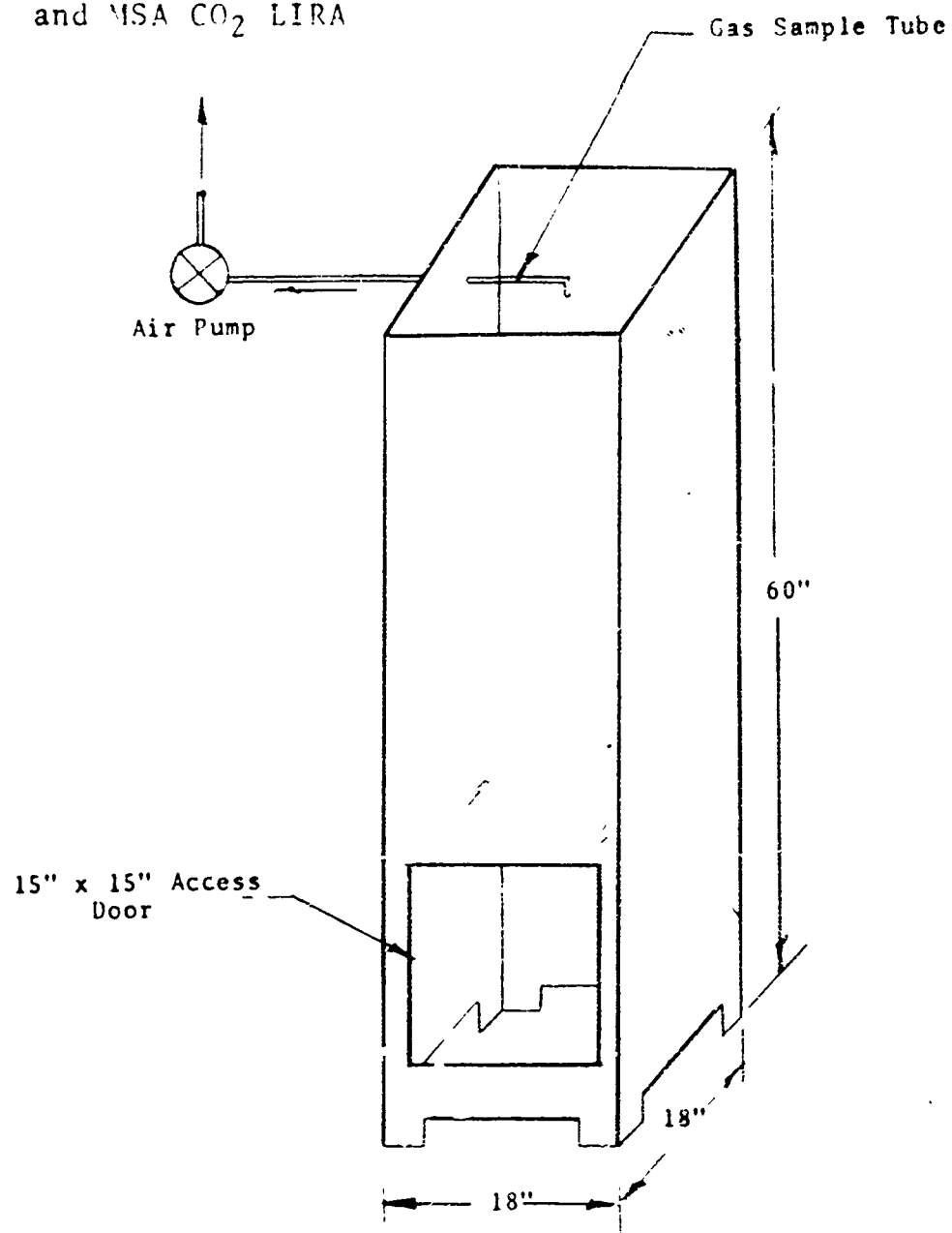


FIG. 4 - COMBUSTION CELL TO MONITOR FLUE  
GAS FROM CARBON HEATING UNIT

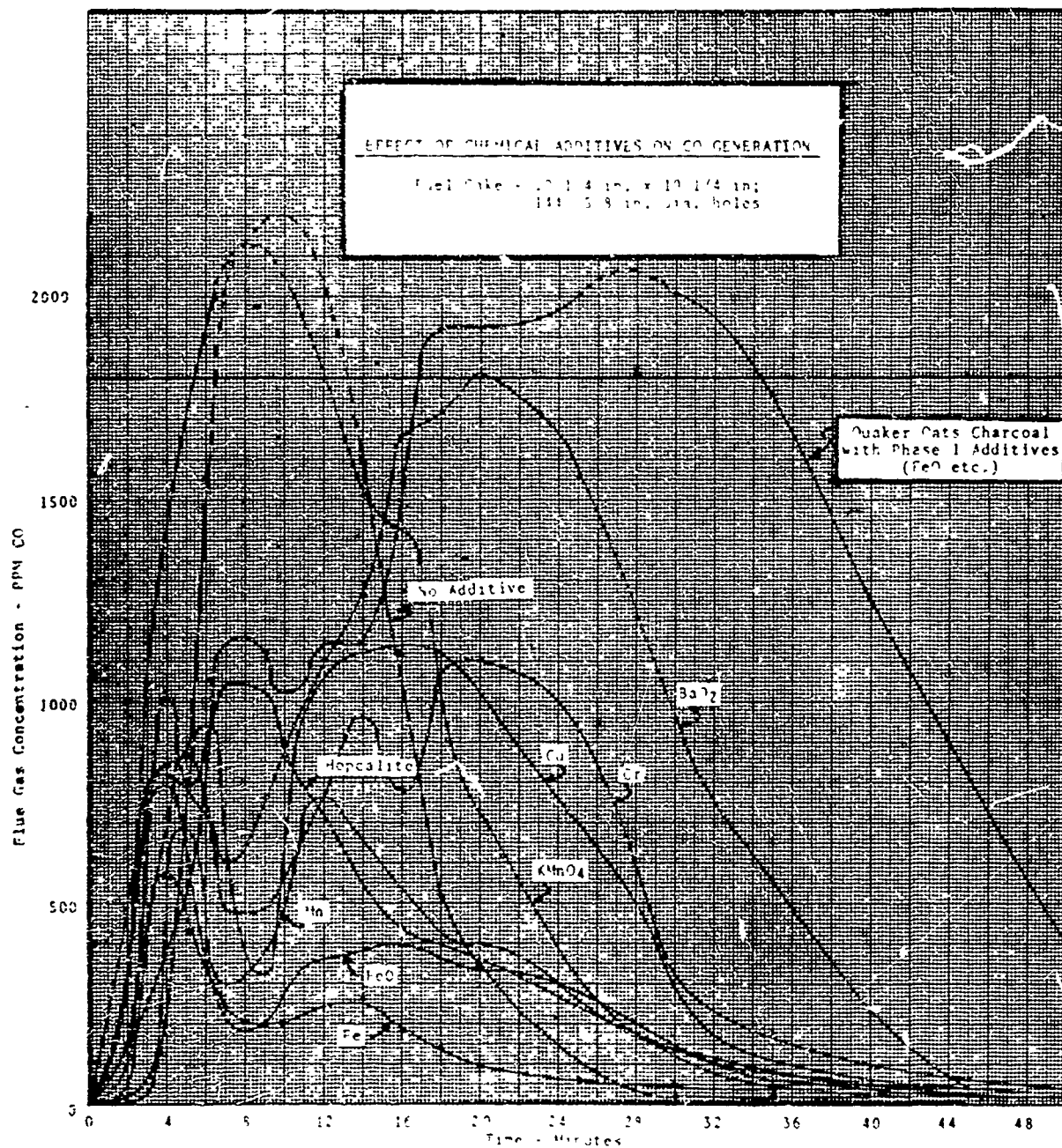


FIG 5 = CARBON MONOXIDE GENERATED FROM COMBUSTION OF CHARCOAL FUEL



TABLE VI - CHEMICAL ADDITIVE TESTS

| Test No. | Additive   | Cake Wt. (g) | Max. CO (ppm) | Avg. CO (ppm) | Avg. CO <sub>2</sub> (%) | Time to Burn (min) | Thermal Eff. (cu ft) | Total CO (cu ft) | Ratio (cu ft CO/lb C) | Burning Rate lb C/min | Time to Boil (min) | Comments                                      |
|----------|--|--------------|---------------|---------------|--------------------------|--------------------|----------------------|------------------|-----------------------|-----------------------|--------------------|---|
| 62       | Mn   | 405          | 840           | 432           | 0.542                    | 48                 | 38.8                 | 2.27             | 2.6                   | 0.0186                | 9-1/2              | Little smoke or odor.                         |
| 63       | Mn   | 363          | 760           | 437           | 0.407                    | 38                 | 36.5                 | 2.57             | 3.2                   | 0.0186                | 9-3/4              | Little smoke or odor.                         |
| 64       | FeO  | 491          | 790           | 326           | 0.522                    | 43                 | 35.5                 | 2.03             | 1.9                   | 0.0212                | 10                 | Little smoke or odor.                         |
| 65       | Hopcalite  | 241          | 1040          | 550           | 0.460                    | 43                 | 38.4                 | 1.90             | 3.6                   | 0.0126                | 12                 | Weak cake - little smoke or odor.             |
| 66       | Cu   | 328          | 1140          | 603           | 0.395                    | 48                 | 36.6                 | 3.30             | 4.6                   | 0.0161                | 12                 | Little smoke or odor.                         |
| 67       | Cr   | 371          | 1100          | 555           | 0.417                    | 48                 | 37.0                 | 3.26             | 4.0                   | 0.0170                | 12                 | Little smoke or odor.                         |
| 68       | BaO <sub>2</sub>   | 357          | 1810          | 895           | 0.444                    | 43                 | 38.8                 | 4.75             | 6.0                   | 0.0183                | 11                 | Little smoke or odor.                         |
| 69       | NaHCO <sub>3</sub>   | 292          | 2000          | 918           | 0.471                    | 48                 | 40.5                 | 3.75             | 5.9                   | 0.0194                | 10                 | Little smoke or odor.                         |
| 70       | FeO**  | 724          | 2000          | 987           | 0.243                    | 63                 | 24.2                 | 19.4             | 12.1                  | 0.0253                | 12-1/2             | Noise smoke and odor than with air float.     |
| 71       | None***  | 467          | 2000          | 1060          | 0.21                     | 33                 | 43.4                 | 15.1             | 14.7                  | 0.0313                | 8                  | Little smoke or odor.                         |
| 72       | Wheelerite   | 484          | 1700          | 727           | 0.50                     | 50                 | --                   | --               | --                    | --                    | 7-1/4              | Ammonia fumes.                                |
| 73       | Pb(C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> ) <sub>2</sub> | 477          | 2000          | 1070          | 0.47                     | 43                 | 57.0                 | 5.0              | 7.0                   | 0.0168                | 7-1/2              | Noticeable odor.                              |
| 82       | KMnO <sub>4</sub>  | 146          | 2000          | 1195          | 0.48                     | 50                 | --                   | --               | --                    | --                    | 9                  | Some odor - this blend spontaneously ignited. |

\* See Appendix B for sample calculation.

\*\* Quaker Oats briquettes were crushed and made into a cake with FeO.

\*\*\* Air float charcoal (300 mesh) mixed with starch and sugar but no FeO.

## 2. Briquettes

An attempt was made to impregnate the commercial briquettes with additives. They were soaked with a solution of sodium chlorate (an oxidizing agent) with the hope of accelerating combustion, but this was unsuccessful primarily because of the quantity of smoke evolved during burning.

The briquettes received from Pure Oil Company were treated with a naphtha-base compound. These briquettes also evolved substantial amounts of smoke hence were considered unsuitable.

Grinding the briquettes into smaller particles proved to be the most effective method of improving their combustion characteristics.

## C. Igniter

The characteristics sought in an igniter were low cost and a non-luminous flame. Both Delrin and Celcon, which are similar, possess non-luminous flames and both effectively ignite charcoal.

A series of igniters screened in an evaluation test showed Delrin (No. 4) and Celcon (No. 1) to be the most desirable from the standpoint of performance (Table VII) although both emitted a formaldehyde-like odor. Although complete elimination of odor could be obtained with heat paper, the paper is undesirable because of its cost and high flame-level. Plastic type igniters other than Delrin and Celcon generally have slow, sooty, combustion properties, hence were not acceptable.

Oxidizing solutions (chlorates and nitrates) applied to absorbent papers were unsuccessful because all produced excessive smoke.

Results of tests of various igniters used with charcoal fuel cakes are given in Table VIII. The igniter selected was the 10-mil Delrin sheet to which two 3/8 by 4-inch tabs of nitrocellulose were stapled for quick ignition. (Delrin tabs stapled to the igniter Delrin sheet were less effective than nitrocellulose tabs.) An all-nitrocellulose igniter was unacceptable because of its luminosity (Table VII) and high flame level. However, nitrocellulose tabs were more effective than the Delrin to start ignition, especially at sub-freezing temperatures.

Delrin is a commercial item that can be bought conveniently. The Delrin sheets supplied with the first unit were expensive (approximately \$0.10 each for virgin Delrin made into flawless film).

TABLE VII - SCREEN TESTS TO EVALUATE  
CHARACTERISTICS OF IGNITERS

Sample Size: Tabs, 1/2 in. wide x 4 in. long

| Test No. | Material                             | Specimen Size | Ambient Temp. (°F) | Flame Characteristics            | Smoke              | Odor              | Remarks  |
|----------|--------------------------------------|---------------|--------------------|----------------------------------|--------------------|-------------------|--|
| 1        | Celcon                               | TAB           | 70                 | Non-luminous                     | -                  | Yes               | Looked similar to Delrin. Some dripping.             |
| 2        | Nitrocellulose                       | TAB           | 70                 | Yellow - large flame             | Yes (sooty)        | Yes               |  |
| 3a       | Nitrocellulose (flame retardent)     | TAB-0.010 in. | 70                 | Rather luminous                  | -                  | Some              | All three thicknesses ignited.                       |
| 3b       | Nitrocellulose (flame retardent)     | TAB-0.015 in. | 70                 | Rather luminous                  | -                  | Some              | " " " "  |
| 3c       | Nitrocellulose (flame retardent)     | TAB-0.020 in. | 70                 | Rather luminous                  | -                  | Some              | " " " "  |
| 4        | Delrin                               | TAB           | -20                | Non-luminous                     | -                  | -                 | Screened samples of both painted and unpainted tabs. |
|          | Nitrocellulose                       | TAB           | -20                | Luminous                         | -                  | -                 | All ignited.   |
| 5        | Polyethylene bag                     | TAB           | 70                 | Luminous                         | Yes (sooty)        | Yes               | Rather hard to ignite, quick burning.                |
| 6        | Bagee (Saran)                        | TAB           | 70                 | Luminous                         | Yes                | Yes               | Hard to ignite - but burned fast when it did.        |
| 7        | Wax Paper                            | TAB           | 70                 | Luminous                         | Yes                | Yes paraffin      | Burned fast.   |
| 8        | Nylon                                | TAB           | 70                 | Non-luminous                     | Yes                | Yes               | Self extinguishing.                                  |
| 9        | Polycarbonate                        | TAB           | 70                 | Luminous                         | Yes (sooty)        | Yes               | Very sooty.  |
| 10       | Acetate                              | TAB           | 70                 | -                                | Yes (Heavy)        | Yes               | Self extinguishing.                                  |
| 11       | Polyethylene                         | TAB           | 70                 | Luminous                         | Heavy              | Yes               | Lot of flame. Burned fast.                           |
| 12       | Polypropylene                        | TAB           | 70                 | Not too luminous                 | Heavy, sooty       | Yes objectionable | Heavy smoke, sooty flame, high.                      |
| 13       | PVC                                  | TAB           | 70                 | Yellow                           | Sooty, very        | Yes objectionable | Self extinguishing, hard to ignite.                  |
| 14       | Cellulose acetate                    | TAB           | 70                 | Yellow, very low                 | Sooty, heavy       | Yes objectionable | Very sooty, luminous, high dripping.                 |
| 15       | Vinyl                                | TAB           | 70                 | Very hard to ignite              | Dirty              | -                 | --   |
| 16       | Flexible vinyl                       | TAB           | 70                 | Very luminous - yellow           | Heavy Soot - Dirty | Yes               | Tended to extinguish.                                |
| 17       | Plexiglass G                         | TAB           | 70                 | Very slow burning - yellow flame | Rather Clean       | Rather Clean      | No noticeable drip.                                  |
| 18       | Catalyst heat paper                  | TAB           | 70                 | Very luminous - bright flame     | None               | None              | Ran with 144 holes in paper - worked well.           |
| 19       | Catalyst heat paper slow burn type   | TAB           | 70                 | Very luminous - bright flame     | None               | None              | " " " " "  |
| 20       | Lustzan 1 - 461 Monsanto ARS polymer | TAB-0.015 in. | 70                 | Yellow flame                     | Very sooty         |                   | Not promising.                                       |

TABLE VIII - IGNITION TESTS WITH CHARCOAL FUEL CAKES

| Charcoal Fuel Cakes Description   |  |                      |           |                      |                    |                      |                  |                     |  |
|---|--|----------------------|-----------|----------------------|--------------------|----------------------|------------------|---------------------|--|
| Geometry: 10 1/4 in. x 10 1/4 in. x 1 in; 144 5/8 in. dia. holes                      |  |                      |           |                      |                    |                      |                  |                     |  |
| Composition: Charcoal - 64.8%<br>Starch - 6.2%<br>Sugar - 11.6%<br>Iron Oxide - 17.4% |  |                      |           |                      |                    |                      |                  |                     |  |
| Tests Conducted With 9 1/2 lbs Water and Heat Shield                                  |  |                      |           |                      |                    |                      |                  |                     |  |
| Test No.  | Igniter Identification   | Weight of Cake (gms) | Temp (°F) | Time to Ignite (min) | Time to Heat (min) | Total Time (min)     | Water Temp. (°F) | Water Evap. (lb-oz) | Remarks  |
| 31  | Fuel cake encased in 3-mil polyethylene bag  | 763                  | 70        | 68                   | 0-5                | 12 45                | 54               | 7-5                 | 42.3<br>Tightly sealed cake in present shipping plastic bag slow to start. Took 8 min for bag to burn out. Heated fast after bag was ignited.  |
| 32  | Catalyst Research Corp. heat paper, Type P/N 401811  | 762                  | 81        | 66                   | 0-5                | 27 0                 | 65               | -                   | Fuel was slow to burn even though heat paper burned in 1 sec. The solid sheet of residue from paper blocked cake holes, which probably cut down rate.                                  |
| 33a   | Deirin sheet, 10-mil thick   | 761                  | 82        | 64                   | 0-2                | 11 45                | 57               | 7-7                 | 42.1   |
| 33b   | Nitrocellulose, flame retardant, 10-mil thick  | 762                  | 82        | 66                   | 0-2                | Did not ignite cake. | Failure          | -                   | Smoked and flamed badly for 35 sec. No ignition.   |
| 33c   | Nitrocellulose flame retardant, 20-mil thick   | 763                  | 82        | 66                   | -                  | Did not ignite cake. | Failure          | -                   | Smoked and flamed badly for 35 sec. No ignition.   |
| 34a   | Catalyst Heat paper, Type P/N 401811, perforated with 144 1/2-in. dia. holes   | 763                  | 80        | 70                   | 0-5                | 10 15                | 55               | 8-0                 | 45.1<br>Burned igniter in less than 1 sec. Perforated.   |
| 34b   | Deirin sheet, 10-mil thick perforated with 144 1/2-in. dia. holes  | 765                  | 80        | 71                   | 0-5                | 10 20                | 52               | 7-8                 | 41.8<br>Not as much smoke or drippings. Looks as though optimum efficiency from ignition, thermally. Appears only improvement is from toxic, odors, etc.                               |
| 35c   | Deirin sheet, 10-mil thick no holes  | 762                  | 80        | 68                   | 0-5                | 11 0                 | 53               | 7-10                | 43.4   |
| 36  | Glass filter, 15-mil thick, perforated with 144 1/2-in. dia. holes. Paper treated with 90 gms Fe powder (Type An-3), 10 gms NaClO <sub>3</sub> , 40 cc H <sub>2</sub> O and dried. Fuel cake was painted with mixture made of 7 lb Fe and 29% water. |                      | 82        | 66                   | 0-5                | 24 0                 | 85               | -                   | Reason for slow boiling time was that the solution that the cake was painted with caused a shielded cake surface, thus keeping the air away from the cake. This slowed the combustion. |
| 37a   | Glass filter, 15-mil thick, perforated with 144 1/2-in. dia. holes. Paper treated with 90 gms Fe powder (Type An-3), 10 gms NaClO <sub>3</sub> , 40 cc H <sub>2</sub> O and dried.   | 762                  | 54        | 64                   | 0-2                | 31 0                 | 72               | -                   | Smoked at start only.  |
| 37b   | Heat paper perforated with 144 1/2 in. dia. holes.   | 812                  | 54        | 64                   | 0-2                | 10 30                | 56               | -                   | Bright glow from heat paper.   |

The manufacturers claimed that reworked scrap could lower the cost, possibly to \$0.05 each. Advances in manufacturing could result in extruding Delrin sheets directly, which would also lower the cost.

#### D. Stove Support

The Phase I stove is expensive to manufacture. A lower cost and more compact stove was developed for Phase II. The positioning of the fuel relative to the base and to the bottom of the water container to be heated are important considerations in the design of these stoves. Tests were conducted to determine the optimum positioning of the fuel and the clearances of the stove. Figure 6 shows the effect of distance on boiling water with charcoal fuel cakes. This plot shows that the optimum distance between the base reflector and the under surface of the fuel is approximately 1 inch. This plot also shows that the optimum distance between the top surface of the fuel and bottom surface of the water container is approximately 2-1/2 to 3 inches. These values were used in evaluating stove concepts.

The fan-style stove depicted in Figure 7 was adopted for use in Phase II units. This stove also proved to be the lowest in cost on the basis of estimates from manufacturers. The stove consists of four members held together by a clip. Figure 8 shows details of the stove member. The segments of the stove were made from No. 9 gage steel wire. The fan is folded for packing and is unfolded for use. The middle rod supports the fuel tray. Clearance from the bottom of the stove is 2-1/8 inches. The overall height of the stove is approximately 5 inches.

Figure 9 shows other stove concepts. The fan-style stove appears at the top of the figure. The original model (top left) had three members. Hotter burning fuels develop higher temperatures, thus, the greater strength and stability of a four-member stove was required. The higher temperatures also made it necessary to increase the distance between the base reflector and the bottom of the fuel (from 1 inch to 2-1/8 inches) to prevent the softening and bending of the stove wire.

#### E. Chimney

To lower its cost and yet provide the functions intended, several changes in its design were considered.

If the height of the chimney was reduced from 12 to 8 inches, effective heating could be achieved at less cost.

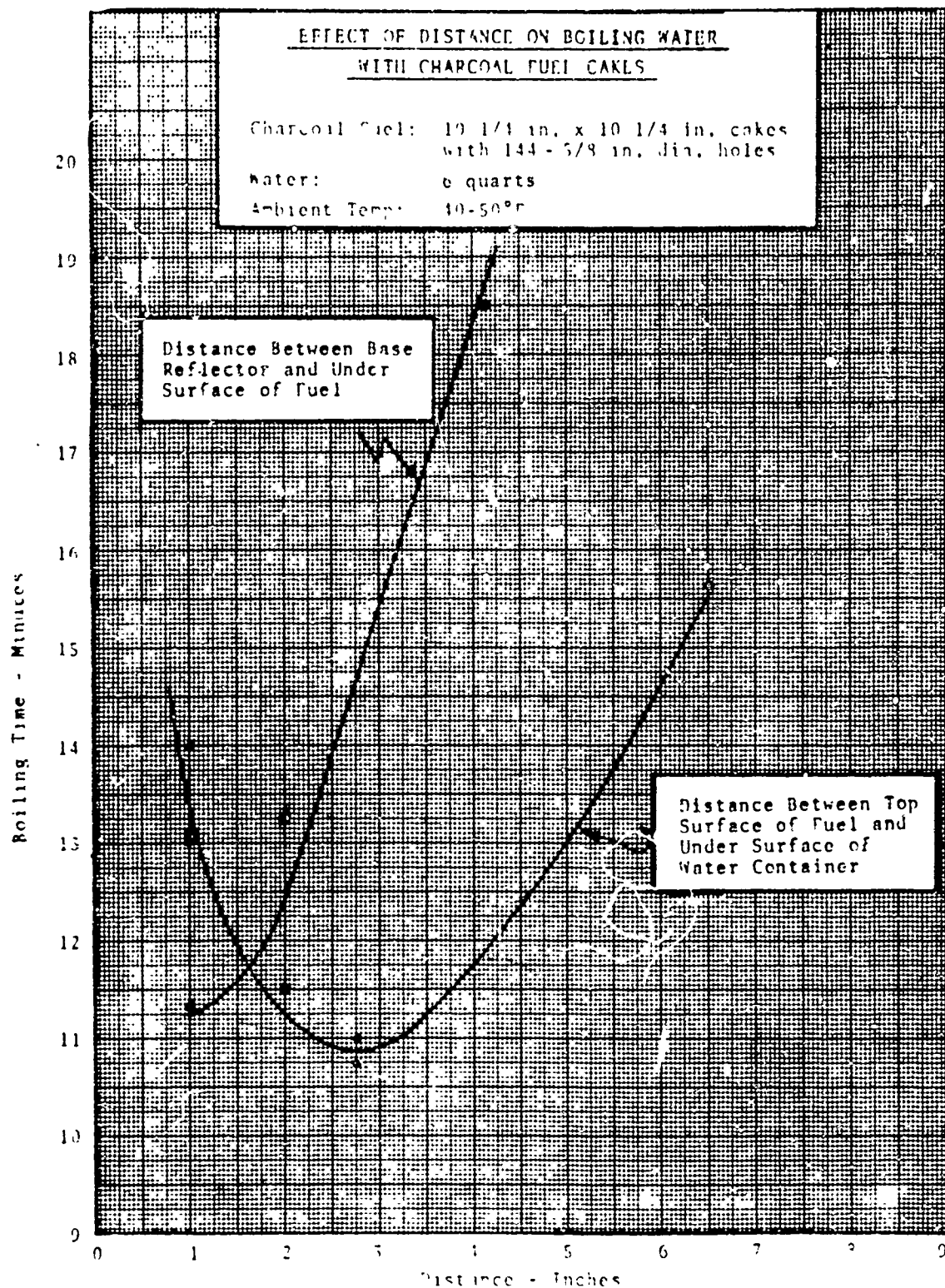


FIG. 6 - DIMENSIONAL FACTORS IN THE DESIGN OF THE STOVE

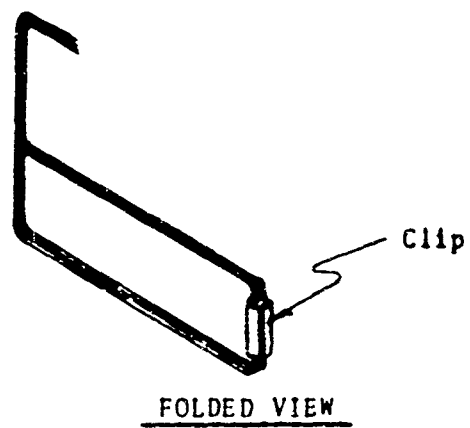
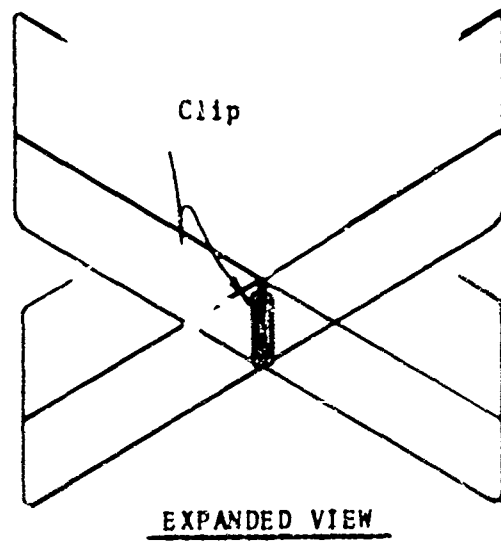


FIG. 7 - FAN-STYLE STOVE SUPPORT FOR PHASE II  
CARBON HEATING UNIT

Notes

1. No. 9 Gage Wire (0.148")
2. Material - C 1008/1010 steel wire
3. Plain Finish

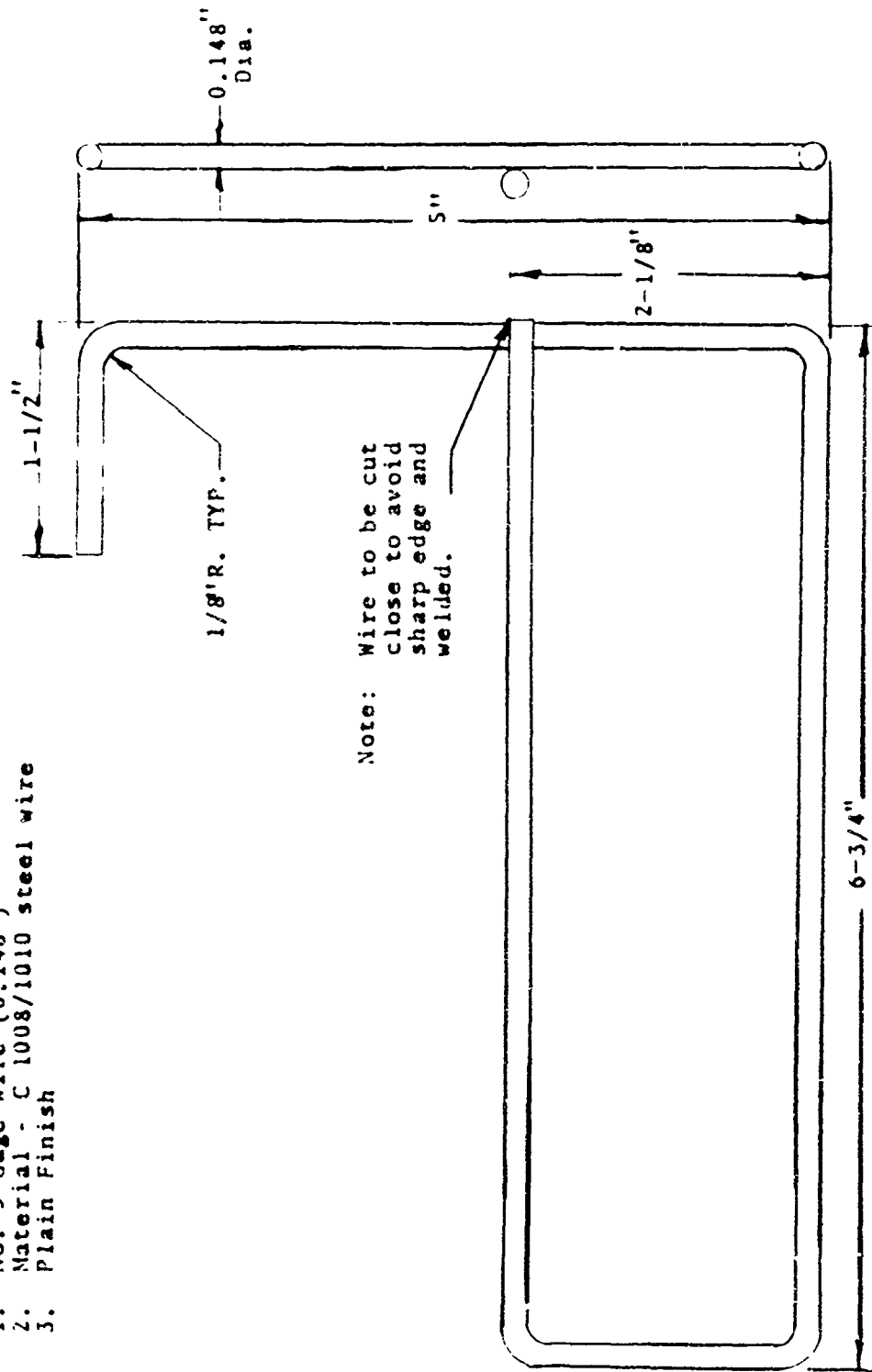


FIG. 8 - DIMENSIONAL DETAIL OF PHASE II CARBON HEATING UNIT STOVE SUPPORT



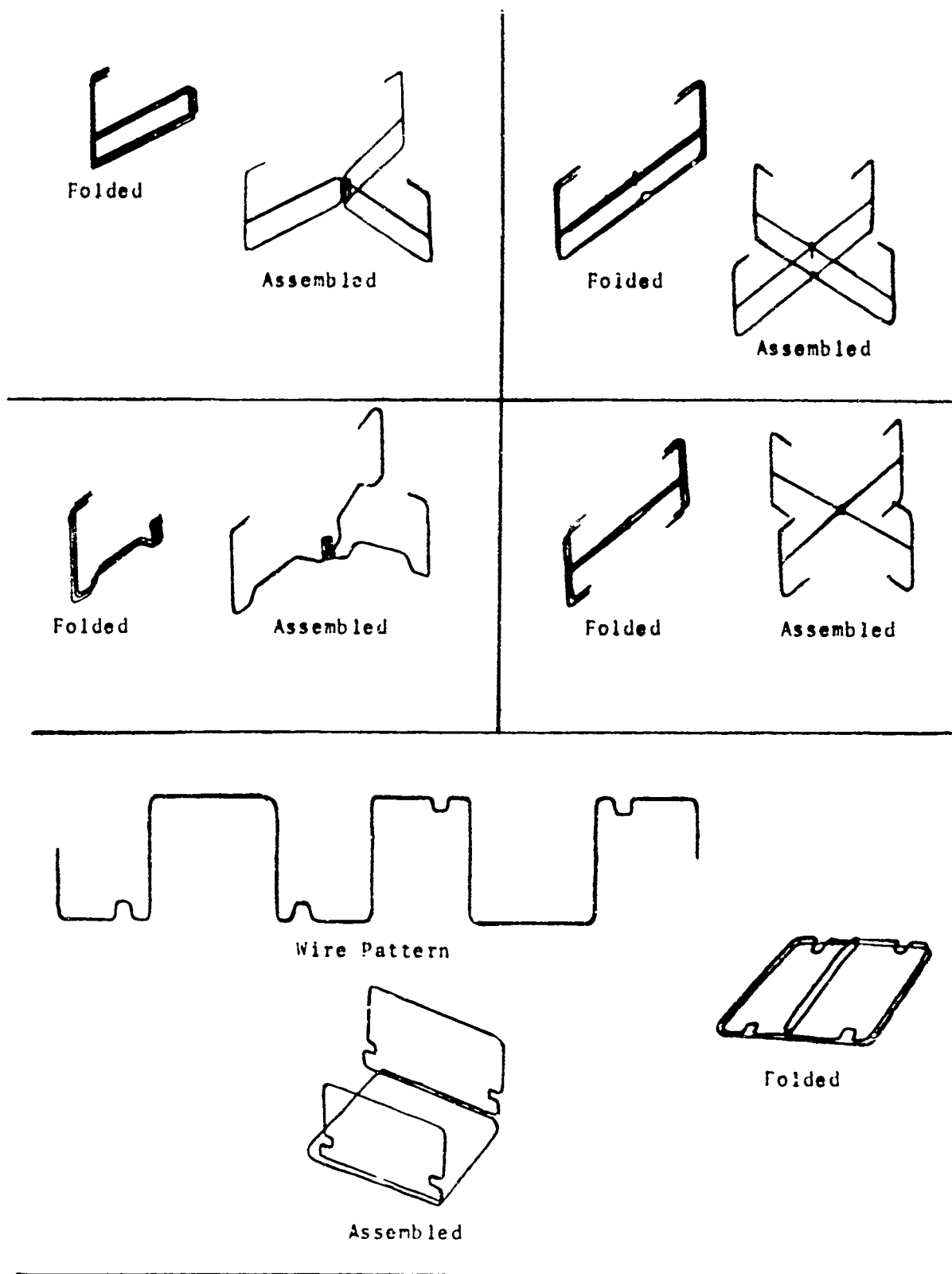


FIG. 9 - SOME STOVE CONCEPTS EVALUATED FOR THE PHASE II CARBON HEATING UNITS

Tests showed that a chimney is essential; it is impossible to bring water to a boil without one. A chimney was fabricated from 1-1/2 mil aluminum foil having two layers of non-reflective olive drab coating. At 8 inches, the water level in the container was at the same elevation as the foil. This heat was adequate to bring water to a boil at ambient conditions without any changes in the former times noted. However, at sub-freezing temperatures, the reduced height required a much longer time to bring water to a boil, therefore the height was retained at 12 inches.

Tests were also made to determine the influence of the reflective surface. When the painted surface was placed inside and the reflective surface outside, no difference in boiling time was noted. This led to the conclusion that the chimney is more of a convective than a radiation shield. The elimination of one layer of coating permitted some reduction in the cost.

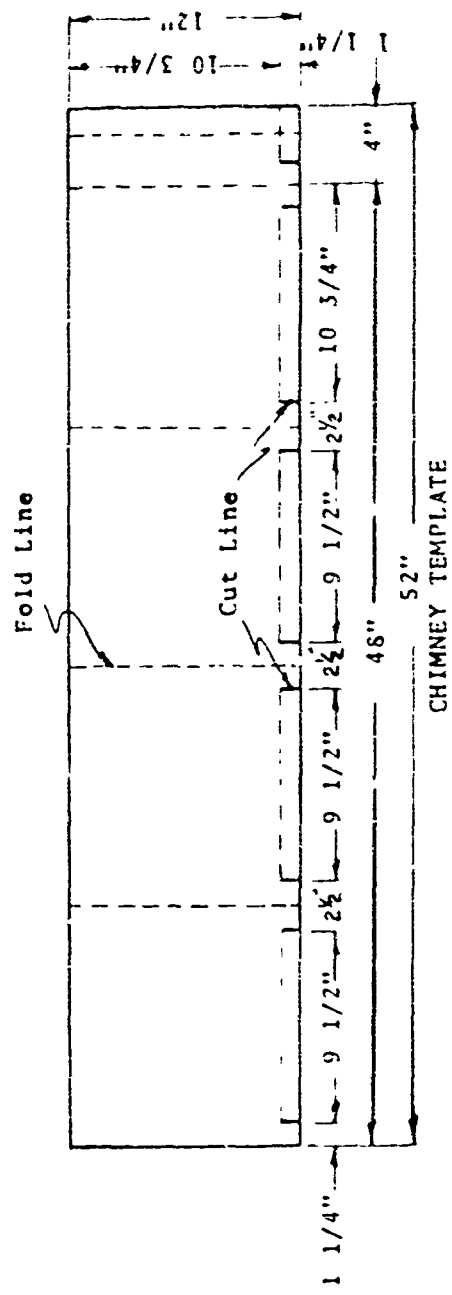
The strength, heat resistance, and cost of substitute materials for aluminum foil were considered. Chimneys were made from glass paper, but glass paper is more expensive and is subject to tearing. Asbestos paper behaved similarly; therefore, both were considered less desirable than aluminum foil.

The chimney design selected for the carbon heating units is shown in Figure 10. This figure shows the layout of the template from which the chimney is fabricated.

#### F. Base Reflector

The base reflector used in Phase I provided support as well as a reflective surface. The reflective surface is important since it reduces boiling time. Tests run without a base reflector required approximately 1-1/2 minutes longer to bring water to the boil. Thus, the reflective surface was considered functional and was retained.

The objection to the Phase I base reflector, which was made of 15-mil aluminum sheet, was its high cost. A 12-inch square of ordinary household aluminum foil provides the same reflective surface, so it was used as the base reflector in the Phase II units. However, aluminum foil provides no support. other means must be provided to support the overall unit. The fiberboard used to package the food containers can serve this purpose. Tests showed that, although fiberboard will char during the ignition and combustion of the heating unit, it does not proceed to the point that rigidity is lost.



1 1/2" Wide Double Fold

Material: Reynolds Aluminum Foil  
1235-0 temper, 1 1/2 mil  
thick dry annealed,  
single olive drab coat  
on mat side.

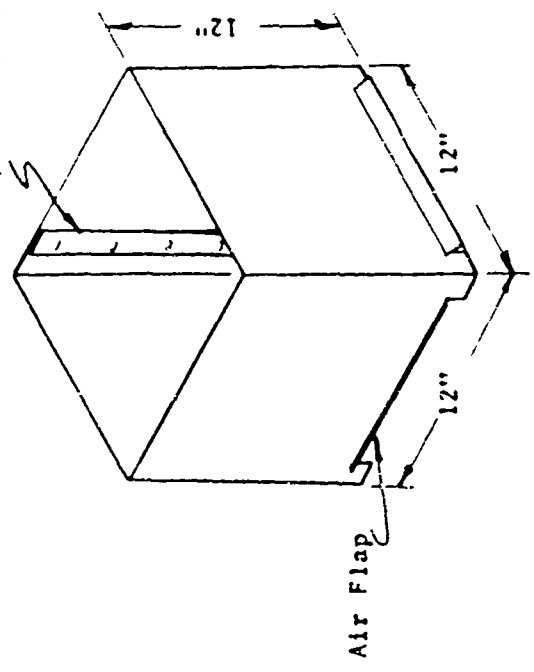


FIG. 10 - CHIMNEY DESIGN

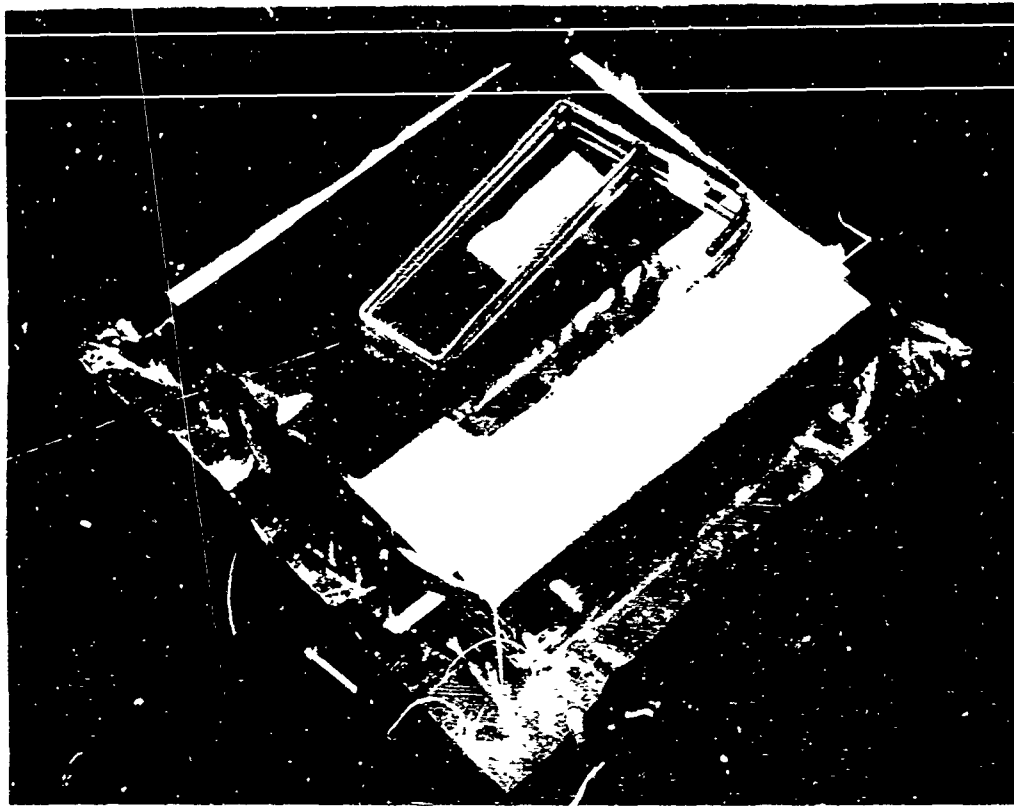
#### IV. Phase II Carbon Heating Unit

##### A. Production

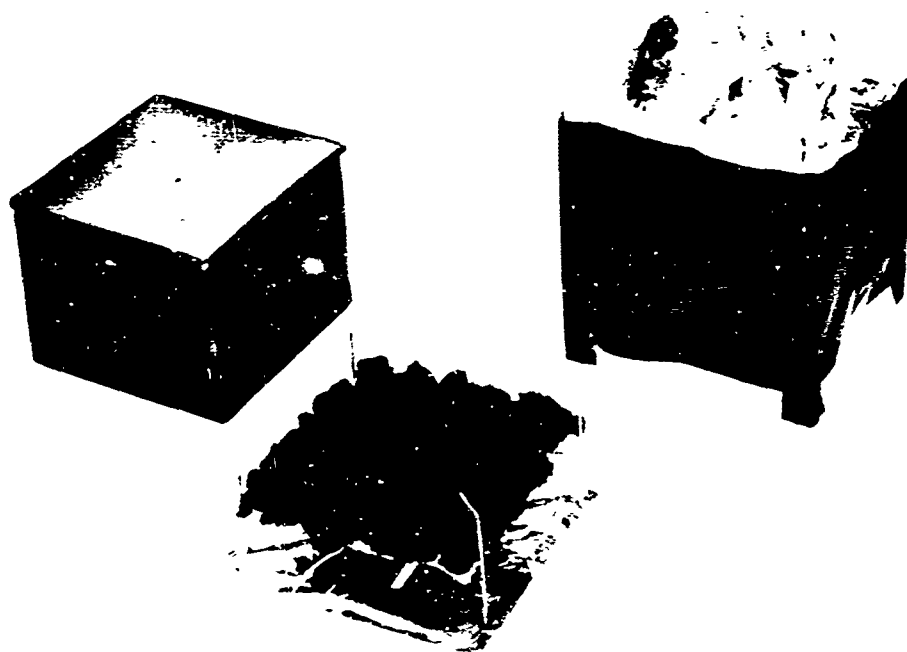
The production requirement of Phase II called for 500 carbon heating units designed to feature improved performance and reduced production time over the earlier models. Commercially available, low-cost gear-shaped charcoal briquettes were substituted for the fuel slab of Phase I. A new stove of more compact design was developed. Changes were made in the basket and base reflector. Maximum fuel efficiency was gained through the optimum geometrical spacing of the fuel and water container. The packaged components of the Phase II unit is shown in Figure 11.

The use of commercially obtainable gear-shaped charcoal briquettes eliminated the need for blending, pressing, drying, carbonizing, wrapping in foil, and unwrapping. To improve the comparatively poor combustion efficiency of the 2 by 7/8-inch briquette, No. 2 mesh (1/2-inch) granules were formed by crushing and screening. This was the only change made. Although smoke and odor were more pronounced with this fuel than with the fuel slab (some smoke was also caused by the coated aluminum shield), this was not thought to be serious since the units are to be used in ventilated areas. Approximately 15 percent of the charcoal was lost as fines in the crushing process. A motorized Champion No. 25 ice crusher and a Sweco Model H-2D separator (18-inch screens) are shown in Figure 12, together with the original briquettes and resultant granules. The ice crusher prongs were more effective in breaking the briquettes than reciprocating jaw-type crushers, for the latter lead to high loss from fines. This equipment processed the granules at the rate of 1 pound per minute, conservatively. In large-scale production, larger crushers and separators could be used.

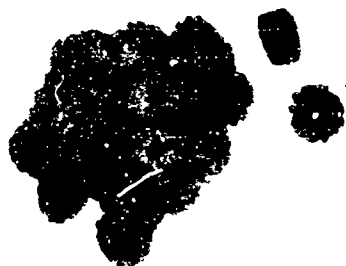
A 10-inch-square by 1-1/2-inch-high steel basket of No. 2 mesh, welded No. 19 wire (standard hardware cloth) was formed from 13-inch squares of mesh (cut from wide rolls) notched at the corners. (The wire can be fabricated into 13-inch rolls.) The baskets were formed by hand with a jurying arbor press to which a block was attached and which was operated by an air cylinder. The block drove the precut wire into a mold where it was formed to shape and could be removed as a basket. For large-scale production, a die and pneumatic press could be used. The baskets were designed to hold 1.8 (+ 0.1) pounds of charcoal granules. First, several granules were placed in the basket (Figure 13); then the Delrin igniter sheet was inserted (its slight elevation due to the granules was found to improve the ignition). The basket was then filled with the rest of



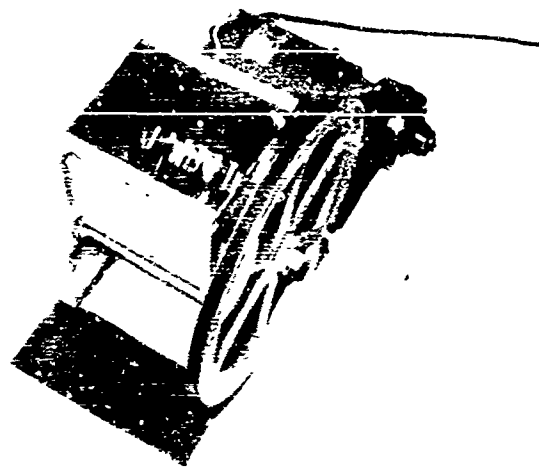
PHASE II CARBON HEATING UNIT  
(Packaged)



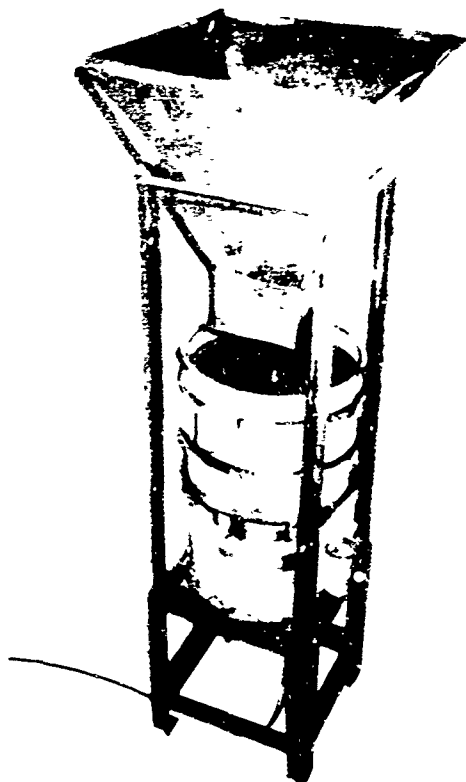
PHASE II CARBON HEATING UNIT  
WITH SIX-IN-ONE MEAL CONTAINER



CHARCOAL BRIQUETTES



CRUSHER



SEPARATOR



FUEL GRANULES

FIG. 12 - PROCESS EQUIPMENT TO REDUCE CHARCOAL BRIQUETTES  
TO GRANULES

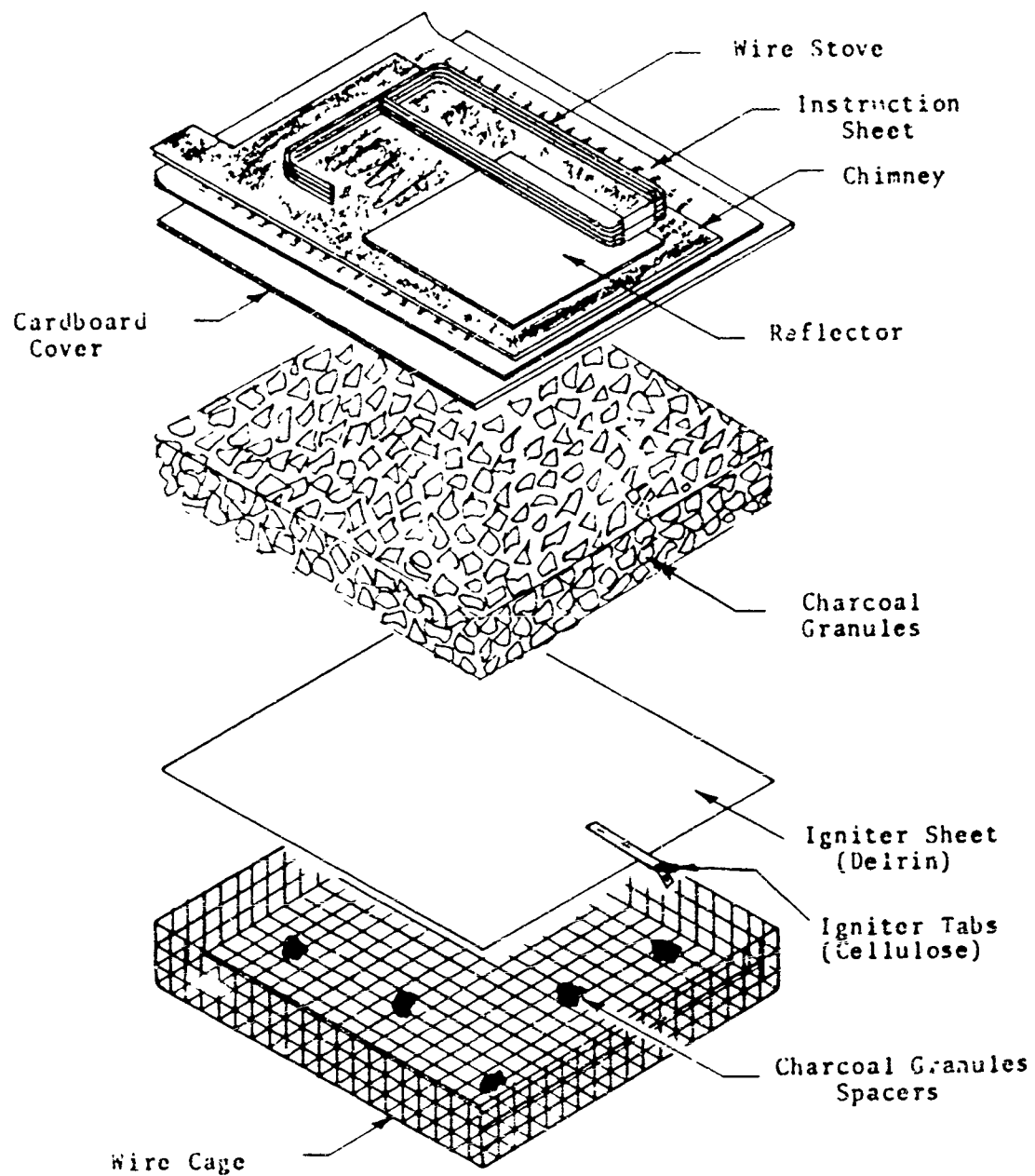


FIG. 13 - PHASE II CARBON HEATING UNIT PACKAGING ASSEMBLY

the granules by means of a volumetrically calibrated scoop. In large-scale production, the basket could be filled directly through a chute extending from the separator (see Flow Chart, Figure 14). A cardboard cover was added to hold the granules within the basket.

For the base reflector, household-type aluminum foil replaced the aluminum sheet. The foil, cut 12 inches square, was folded to a 6-inch square for packaging. It was less expensive and less bulky than the aluminum but not as structurally rigid as a base support. It was decided to use the cardboard cover with foil on top as the base.

The man-hours estimated to complete a Phase II unit was 0.3671 hour (\$1, at \$3 per hour) and the cost of the materials was estimated to be 55 cents, or a total cost of \$1.55 per unit. Exhibits C and D give the breakdown of operations and materials costs on the basis of 100,000 or more units.

## B. Results and Discussion

The packaging of the components is simple, but the production of the unit is less routine. A single shop would be unlikely to have the production diversity required. It would probably be best to subcontract the individual components. For instance, while the processing of charcoal briquettes could well be done by MSARC, the special tooling and equipment required for the stove could best be provided by a specialty wire manufacturer. However, basket forming and chimney production are not attractive to industry, hence the methods as described above, and using a paper-folding machine with adaptations, would probably prove to be the best solution. The cost of the chimney now remains the highest of any of the single-labor items involved. Its design cannot be simplified without sacrificing structural integrity, which is not feasible, and the thin aluminum foil requires careful manual handling and assembly.

## V. Summary and Conclusions

The carbon heating units supplied for Phase I boiled six quarts of water in 10 minutes at an ambient air temperature of 68°F; six quarts of water as ice were thawed and brought to a boil in 21 minutes at a temperature of 50°F and in 30 minutes at 40°F. This high combustion efficiency of the charcoal fuel was obtained by special and relatively expensive processing. The units had to be used in a ventilated tent to prevent carbon monoxide buildup.

In Phase II, high combustion efficiency with lower CO output was sought at decreased cost. Charcoal formulations and fuel supply



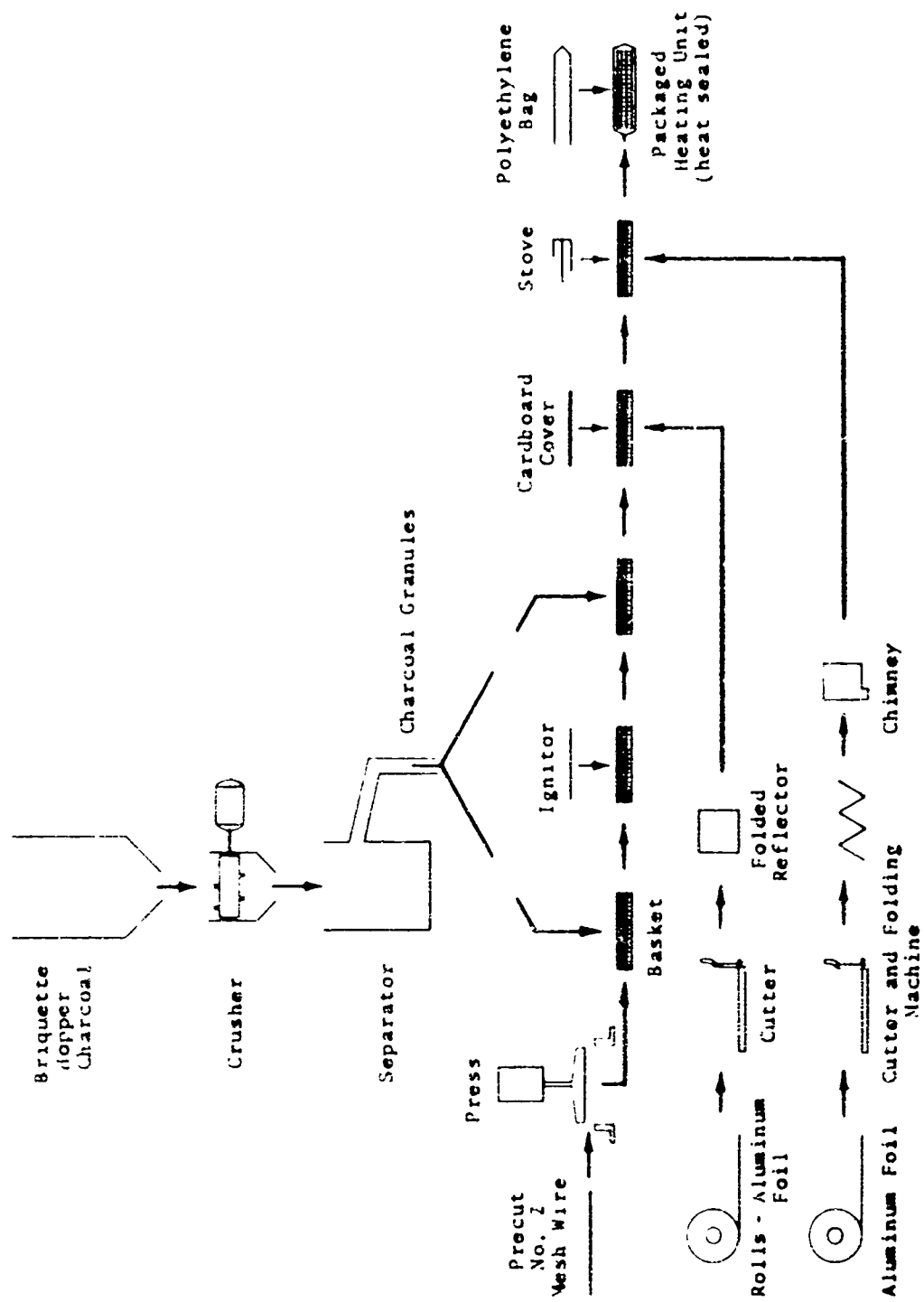


FIG. 14 - PROCESS FLOW SHEET FOR CARBON HEATING UNIT PRODUCTION

## EXHIBIT C

OPERATION SEQUENCE FOR PHASE II  
CARBON HEATING UNIT

| <u>No.</u> | <u>Operation Description</u>   | <u>Each Piece Time</u><br><u>(hr)</u> |                    | <u>Tools</u>             |
|------------|--|---------------------------------------|--------------------|--------------------------|
|            |  | <u>Actual*</u>                        | <u>Projected**</u> |                          |
| 1          | Crush charcoal briquettes and screen                                   | 0.0167                                | 0.0080             | Crusher, separator       |
| 2          | Cut wire and form basket   | 0.1000                                | 0.0200             | Shears, Arbor press      |
| 3          | Precut cellulose tabs and paint, two                                   | 0.0100                                | 0.0050             | Paper cut-term spray gun |
| 4          | Staple tabs to igniter (Delrin)  | 0.0089                                | 0.0039             | Stapler                  |
| 5          | Place igniter sheet into basket and fill 1.5 lb ± 0.1 lb fuel granules | 0.0200                                | 0.0015             | Hopper                   |
| 6          | Fold, cut form and staple chimney                                      | 0.1050                                | 0.0500             | Shears, table staplet    |
| 7          | Cut and fold base reflector  | 0.0100                                | 0.0075             | Shears                   |
| 8          | Assemble contents and pack in plastic bag                              | 0.0385                                | 0.0300             | Bench                    |
| 9          | Heat-seal bag  | 0.0250                                | 0.0300             | Heat sealer              |
| 10         | Wrap and pack bags in carton (10/carton)                               | 0.0140                                | 0.0140             | Bench                    |
| 11         | Crates, stencil ship   | 0.0090                                | ---                | Bench                    |
| Total (hr) |  | 0.3671                                | 0.1699             |                          |

\*For 500 units delivered in Phase II.

\*\*On basis of 100 000 or more

## EXHIBIT D

PROJECTED MATERIAL COST ESTIMATE FOR PHASE II  
CARBON HEATING UNIT

(on basis of 100,000 or more)

| Item  | Unit Cost<br>(\$) |
|---|-------------------|
| 1 Fuel, 1.8 lb @ \$0.05/lb, Quaker Oats Co.,<br>Chicago, Illinois   | 0.0900            |
| 2 Stove, Anchor Wire Specialty, Homestead,<br>Pennsylvania  | 0.1669            |
| 3 Wire basket, Wickwire Bros., Inc., Cortland,<br>New York  | 0.0945            |
| 4 Delrin igniter, Danielson Mfg. Co., Danielson,<br>Connecticut   | 0.0462            |
| 5 Chimney (3-1/2 lb, Olive Drab color)<br>Reynolds Metals Co.   | 0.0965            |
| 6 Base reflector, aluminum foil, Bennett Paper<br>Co., Pittsburgh, Pa.                                    | 0.0014            |
| 7 Cardboard cover, Keystone Box Company,<br>Pittsburgh, Pennsylvania                                      | 0.0100            |
| 8 Polyethylene bag, Ken Covers, Lower Burrell,<br>Pennsylvania  | 0.0221            |
| 9 Instruction sheet   | 0.0005            |
| 10 Cardboard carton (pro-rated for 10 units<br>per box) Keystone Box Company, Pittsburgh,<br>Pennsylvania | 0.0262            |
| Total   | \$0.5543          |

Note: Figure 12 illustrates individual components  
arrangement of the Phase II Carbon Heating  
Unit.

geometries were studied and value analyses performed. To lower the CO output, the air-float charcoal was treated and blended with oxidizing agents. The most effective of these was iron powder and iron oxide, with manganese powder the next best. The special blending increased the cost and did not appear to completely eliminate the CO, which continued to be produced in concentrations that would be dangerous in an unventilated 5-man Army tent.

Heating efficiency was found to be strongly influenced by the geometry of the fuel and its position in the unit. The 5/8-inch hole size was found to be the optimum; a reduction of hole size to 3/8-inch increased boiling time by six minutes. Gear-shaped charcoal briquettes were tested but a layer of these was not as effective as the Phase I fuel unit. A higher surface-to-volume ratio was achieved with the briquettes by crushing them to nominal 1/2-inch granules. A separation of 1-5/8 inches between the top surface of the fuel and the bottom of the water container, and of 2-1/8 inches between the base reflector and the bottom surface of the fuel, was found to produce optimum heating efficiency.

Consideration of the type of charcoal (commercially available briquettes) required and of its design features led to the conclusion that the Phase II unit is more adaptable to bulk manufacture would substantially reduce the cost. In mass production, the cost of material was \$0.55 and the cost of the labor was \$1.00 (0.367 man-hours/unit at \$3.00/hour), or a total of \$1.55. The projected cost of the labor was \$0.51 (0.17 man-hours/unit at \$3.00/hour), which would total \$1.06. This is approximately one-fifth the cost of the Phase I unit. This lower cost is achieved at some sacrifice in performance, but six quarts of water can still be boiled in 15 minutes (as against 10) at 68°F and six quarts of ice in approximately 30 minutes (as against 21 at 50°F) at 46°F ambient. (See Section B under the discussion of the Experimental Program.)

## APPENDIX A

### INSTRUCTIONS FOR ASSEMBLY AND USE OF EXPENDABLE CHARCOAL HEATER

WARNING: DO NOT BURN IN A TENT OR NON-VENTILATED AREA. DO NOT HAVE FACE, BODY, OR CLOTHING OVER STOVE WHILE BURNING FUEL. IN STRONG WIND, EXERCISE CARE TO PREVENT WINDSHIELD AND FOIL BASE FROM BEING BLOWN AWAY

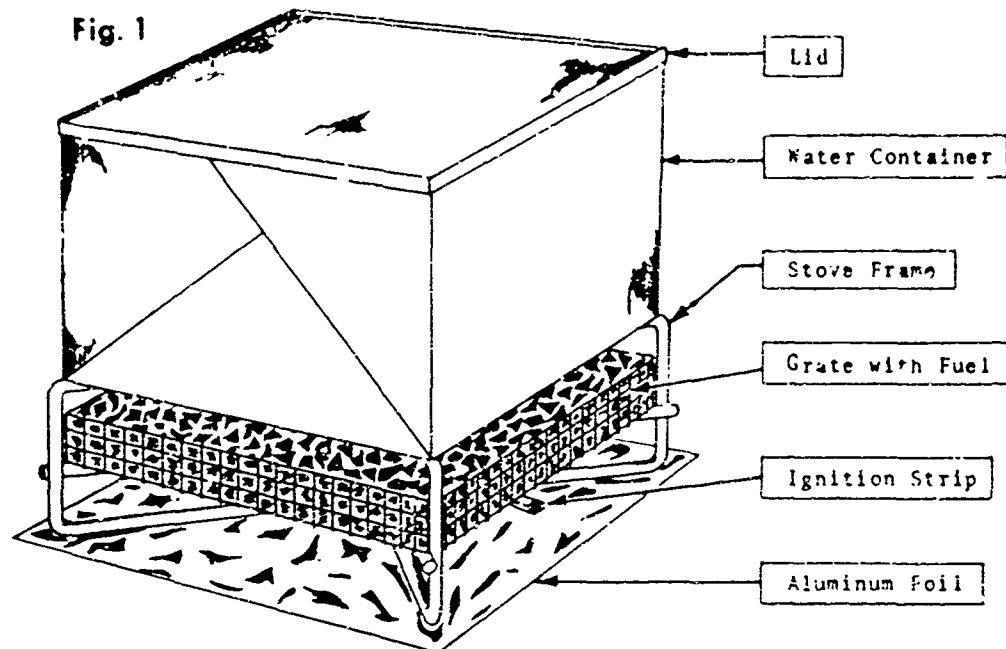
#### Parts of Heater: (see attached figure)

1. Aluminum foil base (Figure 1).
2. Grate containing igniter sheet with colored igniter strips and fuel (Figure 1).
3. Folding four-leg stove frame to support water container and fuel grate (Figure 1).
4. Aluminum foil windshield with OD coating on outside (Figure 2). (Water container, lid and fiberboard box are a part of the meal package, Figure 1).

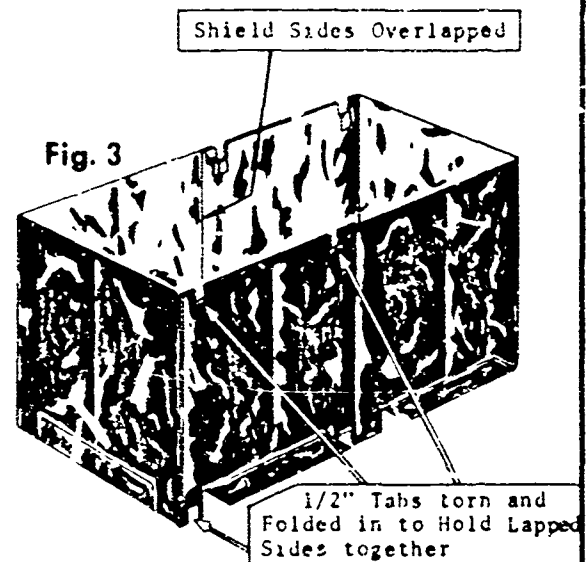
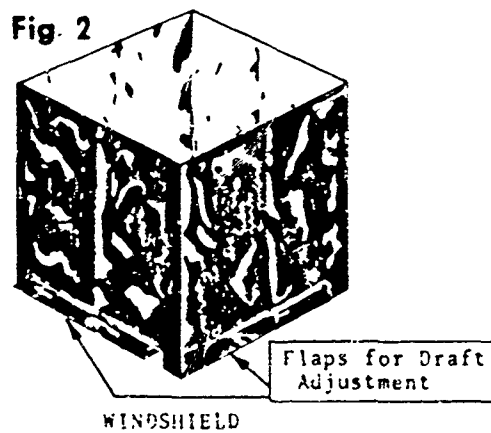
#### Assembly of Heater for Six-In-One Meal:

1. Unfold and place aluminum foil base on level ground cleared of burnable materials. Select a protected location, making use of a hillside, tree, vehicle, or other object as a wind screen. On ice, snow, or mud, place the foil base on the flattened fiberboard box from the meal package.
2. Unfold stove legs so they are equidistant from each other and place upright with cross-pieces down and prongs up (Figure 1).
3. Remove fiberboard cover from top of fuel grate. Slide fuel grate onto center of stove, spreading stove legs apart as necessary. A stove leg should be placed at each corner of grate.

# EXPENDABLE CHARCOAL HEATER COMPONENTS



STOVE WITH 6-IN-1 WATER CONTAINER



4. Place Stove with grate on foil base so that the colored igniter strip faces into any wind.
5. Place aluminum container of the six-in-one meal with the required amount of water on the supports of the stove. Fit cover tightly. If necessary, place stones on cover to hold in place.
6. For best performance, unfold windshield and adjust flaps (Figure 2) according to wind conditions:

Little or no wind, leave open (folded up) all flaps.

Moderate wind, leave open the two flaps on opposite sides of shield.

High winds, have flap on one side open. Avoid exposing shiny surface of flaps.

7. Place windshield around water container and stove with draft openings next to ground and with the flap open on side of igniter strips.
8. Ignite charcoal by holding one, two, or three matches lighted at once under the exposed colored igniter strip. In high winds, shield the stove until the fuel is glowing.

Assembly of Heater for Twenty-Five-In-One Meal:

1. Use four heaters.
2. Assemble four heaters as for the six-in-one meal, using two heaters placed side by side for each of the two sections (top and bottom of meal container). Be sure the colored igniter strip of each heater faces into the wind. If fiberboard base is required, tear meal package carton into two pieces and use one as a base under the foil reflector for each two stoves.
3. Place one-half of the total required water into each of the two sections of the container. Place each section over two heaters.

4. Cover each section of the container with the coated aluminum foil which is included in the twenty-five-in-one meal package. Place foil with coated side up and press edges down around container. This cover is required to reduce heat losses.
5. To make a large shield (Figure 3) for each pair of stoves:
  - a. Unfold two windshields and remove staples or cut the shield down the fold at the stapled corner.
  - b. Combine the shields by overlapping the ends of one shield with the ends of the other shield for 12 inches (one full side) (Figure 3).
  - c. Fasten the overlapping portions of the shield together at top and bottom by tearing two 1/2-inch wide 1/2-inch long tabs and folding tabs in (Figure 3).
6. Adjust flaps so that at least two flaps next to each other are open under high wind conditions and four or more flaps are opened under less severe wind conditions (See step 4 of instruction for six-in-one meal).
7. Place windshield around the large water container and the two stoves with the draft openings next to the ground and the two flaps opened on the side of the igniter strips.
8. Ignite fuel in each stove according to step 6 of instructions for the six-in-one meal.



4. Place Stove with grate on foil base so that the colored igniter strip faces into any wind.
5. Place aluminum container of the six-in-one meal with the required amount of water on the supports of the stove. Fit cover tightly. If necessary, place stones on cover to hold in place.
6. For best performance, unfold windshield and adjust flaps (Figure 2) according to wind conditions:

Little or no wind, leave open (folded up) all flaps.

Moderate wind, leave open the two flaps or opposite sides of shield.

High winds, have flap on one side open. Avoid exposing shiny surface of flaps.

7. Place windshield around water container and stove with draft openings next to ground and with the flap open on side of igniter strips.
8. Ignite charcoal by holding one, two, or three matches lighted at once under the exposed colored igniter strip. In high winds, shield the stove until the fuel is glowing.

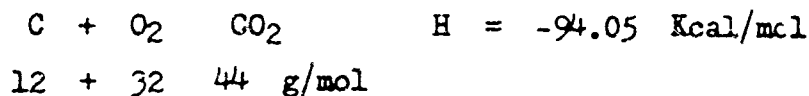
Assembly of Heater for Twenty-Five-In-One Meal:

1. Use four heaters.
2. Assemble four heaters as for the six-in-one meal, using two heaters placed side by side for each of the two sections (top and bottom of meal container). Be sure the colored igniter strip of each heater faces into the wind. If fiberboard base is required, tear meal package carton into two pieces and use one as a base under the foil reflector for each two stoves.
3. Place one-half of the total required water into each of the two sections of the container. Place each section over two heaters.

4. Cover each section of the container with the coated aluminum foil which is included in the twenty-five-in-one meal package. Place foil with coated side up and press edges down around container. This cover is required to reduce heat losses.
5. To make a large shield (Figure 3) for each pair of stoves:
  - a. Unfold two windshields and remove staples or cut the shield down the fold at the stapled corner.
  - b. Combine the shields by overlapping the ends of one shield with the ends of the other shield for 12 inches (one full side) (Figure 3).
  - c. Fasten the overlapping portions of the shield together at top and bottom by tearing two 1/2-inch wide 1/2-inch long tabs and folding tabs in (Figure 3).
6. Adjust flaps so that at least two flaps next to each other are open under high wind conditions and four or more flaps are opened under less severe wind conditions (See step 4 of instruction for six-in-one meal).
7. Place windshield around the large water container and the two stoves with the draft openings next to the ground and the two flaps opened on the side of the igniter strips.
8. Ignite fuel in each stove according to step 6 of instructions for the six-in-one meal.

APPENDIX B  
SAMPLE CALCULATIONS

1. Theoretical heat available per pound of carbon,  $q_{\text{theor.}}$



$$\frac{94.05 \text{ Kcal}}{\text{mol}} \times \frac{1000 \text{ cal}}{\text{Kcal}} \times \frac{\text{mol}}{44 \text{ g}} \times \frac{\text{BTU}}{252 \text{ cal}} \times \frac{454 \text{ g}}{\text{lb}} =$$

$$3850 \text{ Btu/lb CO}_2$$

$$q_{\text{theor.}} = \frac{3850 \text{ BTU}}{\text{lb CO}_2} \times \frac{44 \text{ lb CO}_2}{12 \text{ lb C}} = 14,100 \text{ Btu/lb carbon}$$

Allowances for inerts in charcoal = 11

Heat available in charcoal =  $q = 12,500 \text{ Btu/lb charcoal}$

2. Thermal efficiency, Test 71 data

(a) Cake weight,  $w = 467 \text{ g}$  or  $1.028 \text{ lb}$

(b) Available heat

$$q_{\text{avail}} = wq = 1.028 (12,500) = 12,900 \text{ Btu}$$

(c) Heat absorbed,  $q_{\text{abs.}}$

Sensible heat by water =  $w_{\text{H}_2\text{O}} c_p dt =$

$$12.5 (1) (212-52) = 2000 \text{ Btu}$$

Latent heat = water evaporated  $\times$  heat

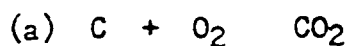
$$\text{vaporization} = 2.5/8 (970) = \underline{2600 \text{ Btu}}$$

$$\text{Total, } q_{\text{abs.}} = 4600 \text{ Btu}$$

$$\text{Thermal efficiency} = \frac{q_{\text{abs.}}}{q_{\text{avail.}}} \times 100 = \frac{4600}{12,900} \times$$

$$100 = 43$$

3. Calculation for CO<sub>2</sub> production, Test 71 data

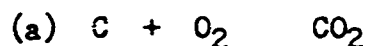


$$\frac{44 \text{ g mol} \times 467 \text{ g}}{\text{mol} \times 12 \text{ g}} = 1660.51 \text{ g CO}_2$$

$$(b) \quad \frac{22.4 \text{ l}}{\text{mol} \times 44 \text{ g}} \times 1660.51 \text{ g} = 845.165 \text{ liters of CO}_2$$

$$(c) \quad 845.165 \text{ l} \times 0.03532 \text{ cu ft/l} = 29.85 \text{ cu ft CO}_2$$

OR



$$\frac{44 \text{ g mol} \times 467 \text{ g}}{\text{mol} \times 12 \text{ g}} \times \frac{1 \text{ lb}}{454 \text{ g}} = 3.66 \text{ lb CO}_2$$

$$(b) \quad \frac{22.4 \text{ b}}{\text{g mol} \times 28.32} \times 454 \text{ g} = 359 \text{ cu ft/mol lb}$$

$$(c) \quad \frac{3.66 \text{ lb} \times \text{mol}}{44 \text{ lb}} \times 359 \text{ cu ft} = 29.9 \text{ cu ft CO}_2$$

$$(d) \quad \text{Volume of air, average CO}_2 \text{ readings (LIRA)} =$$

0.21 by volume.

$$\text{Volume air} = \frac{29.9 \text{ cu ft CO}_2}{0.0021} = 14,250 \text{ cu ft}$$

(e) Volume of CO, average CO readings (LIRA) - 1060 ppm

$$14,250 \times 1060 \times 10^{-6} = 15.1 \text{ cu ft CO}$$

4. Ratio of cu ft of CO per lb carbon

$$\frac{15.1 \text{ cu ft CO}}{1.025 \text{ lb}} = 15.7 \quad \frac{\text{cu ft CO}}{\text{lb carbon}}$$

5. Combustion

Combustion time

Weight of Charcoal - 1.028 lb.

$$\text{rate} = 1.028/33 = 0.0313 \quad \frac{\text{lb carbon}}{\text{minute}}$$

## APPENDIX C

### PROCUREMENT SPECIFICATIONS FOR THE CARBON HEATING UNIT

| <u>Component</u> | <u>Specifications</u>  |
|------------------|--|
| 1. Fuel          | <p>Briquettes, 2-inch diameter x 7/8-inch thick without hickory additive. Briquettes to be crushed to No. 2 mesh granules (1/2-inch particle size). Approximately 1.8 ± .1 pound charcoal per unit.</p> <p>Supplier: Quaker Oats Company<br/>Chicago, Illinois<br/>Price - \$0.05/pound</p>  |
| 2. Stove support | <p>Wire members, four required per stove. Members to be held together with steel clip. No. 9 gage C1008/1010 grade plain finish steel wire. Steel clip, 26 gage commercial quality C.R. steel, C1010 grade steel; temper, half hard; finish No. 1 dull; edge, slit edge.</p> <p>Supplier: Anchor Wire Specialty Co.<br/>543 Dixon Street<br/>P.O. Box 290<br/>Homestead, Pa.<br/>Price - \$0.1669/M (on basis of 100,000 stoves)</p> |
| 3. Chimney       | <p>Roll, Reynolds A1 foil, 1235-0 temper 1-1/2 mil thick dry annealed, single olive drab coat on mat side (3-1/2 pound per ream, 6500 sq in per 1 pound). Approximately 10 chimneys per pound.</p> <p>Supplier: Reynolds Metals Co.<br/>Price - \$0.969/pound</p>  |

| <u>Component</u>   | <u>Specifications</u>  |
|--------------------|--|
| 4. Fuel cage       | <p>No. 2 mesh, 19 gage plain steel welded wire cloth, 26-inch or 39-inch wide rolls 100-200 feet long.</p> <p>Supplier: Wickwire Prothers, Inc.<br/>Cortland, New York 13046<br/>Price - \$9.55/100 sq ft<br/>(on basis of 1,250,000 cages or 1,465,000 sq ft).</p>  |
| 5. Igniter         | <p>Sheet, 10-1/4 inch x 10-1/4 inch (<math>\pm</math> 1/16) x 0.010 (<math>\pm</math> 0.002) inch thick. Danco Acetal Strip (Delrin). Scrap delrin as raw material.</p> <p>Supplier: Danielson Manufacturing Co.<br/>Danielson, Connecticut<br/>Price - \$0.0586 each (on basis of 1,000,000 sheets)<br/>\$0.0637 each (on basis of 500,000 sheets).</p> |
| 6. Reflector       | <p>Roll, aluminum foil, Reynolds household type; 12 in. wide x 0.001 gage.</p> <p>Supplier: Bennett Paper Co.<br/>918 Reckenbach Street<br/>Pittsburgh, Pa. 15212<br/>Price - \$23.89 per 25 lb roll (1770 reflectors at \$0.00135 each).</p>  |
| 7. Cardboard cover | <p>Sheet, 10-1/4 inch x 10-1/4 inch pad, 125-pound cardboard.</p> <p>Supplier: Keystone Box Co.<br/>Pittsburgh, Pa.<br/>Price - \$0.01 each (on basis of 1000).</p>  |
| 8. Plastic bag     | <p>Polyethylene, 15 inch x 15 inch x 3 mil thick.</p> <p>Supplier: Ken Covers<br/>Lower Burrell, Pa. 15069<br/>Price - \$22.00/M less 2%<br/>(on basis of 100,000 and over).</p>   |

Unclassified

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| 11. SUPPLEMENTARY NOTES  | 12. SPONSORING MILITARY ACTIVITY<br>U. S. Army Natick Laboratories<br>Natick, Mass. 01760 |  |
| 13. ABSTRACT<br>Experimental carbon heating units to boil water for reconstituting precooked dehydrated foods were developed at the U. S. Army Natick Laboratories and produced in contractor's pilot plant for field and laboratory study. These were designated as Phase I units. As a result of further experimentation, and based on the test findings, the contractor produced an improved unit that was designated as Phase II.<br><br>Both units consisted of carbon fuel, igniter, stove support, base reflector, and shield or chimney. The Phase I fuel was a charcoal slab with perforations. The reflector was of rigid aluminum. At an ambient temperature of 68°F, this unit boiled 6 quarts of water in 10 minutes and, at an ambient temperature of 46°F, thawed snow or ice and boiled the resultant water in 22 minutes. In Phase II, several types of fuel were developed, the most promising of which was made from commercially available char fuel briquettes broken into approximately 1-inch pieces. Inexpensive fiberboard and aluminum foil replaced the rigid aluminum as reflector and the stove support was made of 4 simple parts. Under the same ambient conditions, these units brought 6 quarts of water to a boil in 14 minutes and thawed snow or ice and boiled the resultant water in 30 minutes.<br><br>Although the Phase II units required slightly more heating time, their cost, estimated at about \$1.00 each in quantities of 100,000, was approximately one-fifth that of the Phase I units. |   |  |



| 14<br>KEY WORDS  | LINK A |    | LINK B |    | LINK C |    |
|------------------|--------|----|--------|----|--------|----|
|                  | ROLE   | WT | ROLE   | WT | ROLE   | WT |
| Development      | 8      |    |        |    |        |    |
| Charcoal         | 2      |    |        |    |        |    |
| Heaters          | 2      |    |        |    |        |    |
| Cooking devices  | 2      |    |        |    |        |    |
| Production       | 8      |    |        |    |        |    |
| Heating          | 4      |    |        |    |        |    |
| Water            | 4      |    |        |    |        |    |
| Meals            | 4      |    |        |    |        |    |
| Military rations | 4      |    |        |    |        |    |

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